



**Focused Feasibility Study**

Former 901/902 Thompson Place  
Sunnyvale, California

*Prepared on Behalf of:*

**Advanced Micro Devices, Inc., Sunnyvale, California**

*Prepared by:*

**AMEC Geomatrix, Inc., Oakland, California**

May 2011

Project OD10160080.2011.4

**AMEC Geomatrix**



May 18, 2011

Project OD10160080.0004

Mr. Max Shahbazian, PG  
San Francisco Regional Water Quality Control Board  
1515 Clay Street, Suite 1400  
Oakland, California 94612


**Subject: Focused Feasibility Study**  
Former 901/902 Thompson Place  
Sunnyvale, California


Dear Mr. Shahbazian:


Please find enclosed the subject report for the former Advanced Micro Devices (AMD) facility located at 901/902 Thompson Place, in Sunnyvale, California, prepared by AMEC Geomatrix, Inc. (AMEC) on behalf of AMD.

In a letter dated November 18, 2010, the Water Board requested that AMD complete a Focused Feasibility Study (FFS) in order to help the Water Board evaluate and select a revised cleanup plan and prepare a revised final site cleanup requirements order. AMEC, on behalf of AMD, has compiled necessary information and technical analyses, as described in this FFS report, to **facilitate the Water Board's decision-making process and accelerate site cleanup.** Please contact either of the undersigned if you have any questions about the report.

Sincerely yours,  
AMEC Geomatrix, Inc.

  
Min-Ying Jacob Chu, PE No. C 74786  
Project Engineer  
Direct Tel.: 510-663-4276  
Direct Fax: 510-663-4141  
E-mail: [jacob.chu@amec.com](mailto:jacob.chu@amec.com)

  
Michael Calhoun, PG No. 8525  
Project Geologist  
Direct Tel.: 510-663-4248  
Direct Fax: 510-663-4141  
E-mail: [michael.calhoun@amec.com](mailto:michael.calhoun@amec.com)

  
Peter Bennett, PG No. 7902, CHG No. 921  
Principal Hydrogeologist  
Direct Tel.: 510-663-4256  
Direct Fax: 510-663-4141  
E-mail: [peter.j.bennett@amec.com](mailto:peter.j.bennett@amec.com)

JC/MC/PB/bfw  
X:\16000s\160080\4000\FFS\_051811\1\_Text, Covers, etc\Letter.doc

Enclosure:

AMEC Geomatrix, Inc.  
2101 Webster Street, 12th Floor  
Oakland, California  
USA 94612-3066  
Tel (510) 663-4100  
Fax (510) 663-4141  
[www.amecgeomatrixinc.com](http://www.amecgeomatrixinc.com)

**AMEC Geomatrix**

ED\_006475C\_00003377-00002



Mr. Max Shahbazian, PG  
San Francisco Regional Water Quality Control Board  
May 18, 2011  
Page 2

cc:

Mr. Do Cao  
Advanced Micro Devices, Inc.  
One AMD Place  
Sunnyvale, California 94088  
(408) 749-6126  
[Do.cao@amd.com](mailto:Do.cao@amd.com)

Mr. Brett Stringer  
Advanced Micro Devices  
One AMD Place  
Sunnyvale, California 94088  
[Brett.stringer@amd.com](mailto:Brett.stringer@amd.com)

**Electronic Copies:**

Mr. Ron Staricha  
City of Sunnyvale  
Public Safety Department, Fire and Environmental Services  
P.O. Box 3707  
Sunnyvale, California 94088-3707  
[rstaricha@ci.sunnyvale.ca.us](mailto:rstaricha@ci.sunnyvale.ca.us)

Mr. George Cook  
Santa Clara Valley Water District  
5750 Almaden Expressway  
San Jose, California 95118  
[gcook@valleywater.org](mailto:gcook@valleywater.org)  
[lustop@valleywater.org](mailto:lustop@valleywater.org)

Mr. Matt Salazar  
United States Environmental Protection Agency, Region IX  
75 Hawthorne Street  
Mailcode SFD-7-4  
San Francisco, California 94105  
[salazar.matt@epamail.epa.gov](mailto:salazar.matt@epamail.epa.gov)



Mr. Max Shahbazian, PG  
San Francisco Regional Water Quality Control Board  
May 18, 2011  
Page 3

Klaus Rohwer, PG, REA II  
Equipoise Corporation  
26395 Jefferson Avenue, Suite A  
Murrieta, California 92562  
p. 951.696.7217  
f. 951.696.9527  
[KPRohwer@earthlink.net](mailto:KPRohwer@earthlink.net)

Mr. Pawan Sharma  
Camp Dresser McKee  
100 Pringle Avenue  
Walnut Creek, California  
[sharmapk@cdm.com](mailto:sharmapk@cdm.com)

Shau-Luen Barker  
Project Realty LLC  
15313 W. 95th Street  
Lenexa, Kansas 66219  
[Shauluen@aol.com](mailto:Shauluen@aol.com)

Mr. John Wesley Hawthorne  
Locus Technologies  
299 Fairchild Drive  
Mountain View, California 94043  
[hawthornej@locustec.com](mailto:hawthornej@locustec.com)

Parviz Vaghti  
Chief Financial Officer  
Summit Commercial Properties, Inc.  
100 N. Sepulveda Blvd, Suite 1210  
El Segundo, California 90245  
[pvaghti@scprop.net](mailto:pvaghti@scprop.net)



## TABLE OF CONTENTS

	Page
EXECUTIVE SUMMARY .....	1
1.0 INTRODUCTION .....	1
2.0 SITE BACKGROUND .....	1
3.0 GROUNDWATER REMEDIATION PERFORMED SINCE 1983 .....	2
3.1 Current Magnitude and Extent of Concentrations Compared to Cleanup Standards and Screening Levels .....	2
4.0 ALTERNATIVES CONSIDERED IN THE FOCUSED FEASIBILITY STUDY (FFS) .....	3
5.0 PROPOSED ALTERNATIVE .....	3
6.0 HOW THE PROPOSED ALTERNATIVE ADDRESSES THE NINE EVALUATION CRITERIA IN THE GUIDANCE .....	4
7.0 CONCLUSIONS .....	5
1.0 INTRODUCTION .....	1
1.1 PURPOSE AND ORGANIZATION OF REPORT .....	1
1.2 SITE LOCATION AND CURRENT USE .....	1
1.3 SITE OPERATION HISTORY AND CHRONOLOGY .....	2
1.4 SITE CHARACTERIZATION .....	3
1.4.1 Site Hydrogeology .....	3
1.4.1.1 Hydrostratigraphic Zones .....	3
1.4.1.2 Groundwater Flow .....	4
1.4.1.3 Aquifer Properties .....	5
1.4.2 Nature and Extent of Constituents of Concern in Soil .....	6
1.4.3 Nature and Extent of COCs in Groundwater .....	6
1.4.4 Constituents of Concern .....	6
1.4.5 Current COC Distributions in Groundwater .....	7
1.4.5.1 COC Concentrations in the ISB Treatment Area .....	7
1.4.5.2 COC Concentrations in the Area Upgradient of the ISB Treatment Area .....	8
1.4.5.3 COC Concentrations in the Downgradient Off-Site Monitoring Wells .....	8
1.4.5.4 COC Concentrations in the B3 Zone .....	9
1.4.6 Historical Concentration Trends in Site Monitoring Wells .....	9
1.4.6.1 ISB Treatment Period (2005–2010) .....	9
1.4.6.2 Groundwater Extraction and Treatment Period (1983-2002) .....	10
1.4.7 Ambient COC Concentrations in Groundwater .....	11
1.5 SUMMARY OF SITE RISKS .....	13
1.5.1 Risks to Human Health .....	13
1.5.2 Ecological Risks .....	14
1.6 FATE AND MOBILITY OF COCs .....	15
1.6.1 Degradation and Transformation of Site COCs in Saturated Aquifer .....	15
1.6.2 Transport of Site COCs in Saturated Aquifer .....	15
1.6.3 Influence of Aquifer Heterogeneity on Solute Transport in Saturated Aquifer .....	16
1.6.4 COC Volatilization from Groundwater .....	16
1.7 HISTORY OF REMEDIES IMPLEMENTED FOR SITE CLEANUP .....	17

## TABLE OF CONTENTS

(Continued)

1.8	COMPARATIVE PERFORMANCE EVALUATION FOR PUMP-AND-TREAT AND IN SITU BIOREMEDIATION .....	18
1.8.1	Ex Situ Mass Removal Efficiency .....	18
1.8.2	Change in Concentration Trends .....	19
1.9	POTENTIAL ADVERSE EFFECTS OF HISTORICAL EXTRACTION ACTIVITY .....	20
2.0	REMEDIAL ACTION OBJECTIVES .....	21
2.1	REMEDY AND CLEANUP STANDARDS SELECTED BY REGULATORY AGENCIES .....	21
2.2	APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARs) .....	21
2.3	TO-BE-CONSIDERED CRITERIA AND REMEDIATION GOALS .....	22
2.3.1	Groundwater RBCs for Domestic Use .....	22
2.3.2	Groundwater RBCs for Vapor Intrusion Pathway .....	23
2.3.3	Upgradient Groundwater Concentrations .....	24
2.4	SUMMARY OF REMEDIAL ACTION OBJECTIVES AND PROPOSED SITE-SPECIFIC REMEDIATION GOALS .....	24
3.0	IDENTIFICATION AND SCREENING OF TECHNOLOGIES .....	25
3.1	GENERAL RESPONSE ACTIONS .....	25
3.2	INITIAL SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS .....	26
3.3	SECONDARY SCREENING OF PROCESS OPTIONS .....	26
3.3.1	Effectiveness .....	27
3.3.2	Implementability .....	27
3.3.3	Cost .....	27
3.4	RESULTS OF SECONDARY SCREENING PROCESS OPTIONS .....	27
3.4.1	Groundwater Sampling and Monitoring .....	27
3.4.2	Institutional Controls – Groundwater Access Restriction .....	28
3.4.3	Monitored Natural Attenuation .....	28
3.4.4	Groundwater Extraction .....	28
3.4.5	Groundwater Treatment – Air Stripping .....	29
3.4.6	Groundwater/Vapor Treatment – Carbon Adsorption .....	29
3.4.7	Groundwater Treatment – Ex Situ Biological Processes (Aerobic/Anoxic and Anaerobic Bioreactors) .....	29
3.4.8	In Situ Chemical Reduction .....	30
3.4.9	In Situ Enhanced Anaerobic Microbial Degradation .....	30
3.4.10	Pneumatic Fracturing .....	30
3.4.11	Directional Well .....	31
3.4.12	Discharge – Surface Water .....	31
3.4.13	Discharge – Water Reclamation .....	31
3.4.14	Discharge – Injection Wells .....	31
4.0	DEVELOPMENT OF REMEDIAL ALTERNATIVES .....	31
4.1	ALTERNATIVE 1: NO FURTHER ACTION .....	32
4.2	ALTERNATIVE 2: GROUNDWATER EXTRACTION AND TREATMENT .....	32
4.3	ALTERNATIVE 3: MONITORING NATURAL ATTENUATION IN THE A ZONE AND GROUNDWATER EXTRACTION AND TREATMENT IN THE B ZONES .....	32
4.4	ALTERNATIVE 4: IN SITU BIOREMEDIATION AND MONITORING NATURAL ATTENUATION .....	33

## TABLE OF CONTENTS

(Continued)

4.5	ALTERNATIVE 5: PERMEABLE REACTIVE BARRIER.....	33
5.0	DETAILED EVALUATION OF REMEDIAL ALTERNATIVES.....	34
5.1	EVALUATION CRITERIA.....	34
5.1.1	Threshold Criteria – Overall Protection of Human Health and the Environment.....	35
5.1.2	Threshold Criteria – Compliance with ARARs .....	36
5.1.3	Balancing Criteria – Long-Term Effectiveness and Permanence.....	36
5.1.4	Balancing Criteria – Reduction of Toxicity, Mobility, and Volume through Treatment.....	36
5.1.5	Balancing Criteria – Short-Term Effectiveness .....	37
5.1.6	Balancing Criteria – Implementability .....	37
5.1.7	Balancing Criteria – Cost.....	37
5.2	INDIVIDUAL ANALYSIS OF ALTERNATIVES.....	38
5.2.1	Alternative 1: No Further Action .....	38
5.2.2	Alternative 2: Groundwater Extraction and Treatment (1991 ROD) .....	39
5.2.3	Alternative 3: Monitored Natural Attenuation in the A Zone and Groundwater Extraction and Treatment in the B Zones .....	41
5.2.4	Alternative 4: In Situ Bioremediation and Monitored Natural Attenuation.....	43
5.2.5	Alternative 5: Permeable Reactive Barrier.....	44
6.0	COMPARATIVE ANALYSIS OF ALTERNATIVES .....	46
7.0	RECOMMENDED REMEDIAL ALTERNATIVE .....	46
8.0	REFERENCES .....	47

## TABLES

Table ES-1	Comparison of Remedial Alternatives
Table 1	Site Chronology
Table 2	Well Construction Details
Table 3	Summary of Aquifer Properties
Table 4	Analytical Results for Groundwater Samples – October 2010
Table 5a	Documented TCE Groundwater Sources That Potentially Impact the Site
Table 5b	VOC Concentrations Recently Detected at Upgradient Sites in the A Zone
Table 6a	Historical Groundwater Extraction Rates and VOC Removal and Efficiency
Table 6b	Representative Annual Pumping Rates
Table 7a	Trends of TCE Concentration Change at Selected Wells
Table 7b	Trends of Chlorinated Ethene Concentrations at Selected Wells
Table 8	Groundwater Cleanup Standards
Table 9	Groundwater Cleanup Standards vs. Current U.S. EPA Risk-Based Levels
Table 10	Comparison of Proposed Risk-Based Concentrations and Regulatory Screening Levels
Table 11a	Initial Screening of Remedial Technologies

## TABLE OF CONTENTS

(Continued)

Table 11b	Initial Screening of Supplemental Substrate Delivery and Groundwater Recovery Process Options
Table 12a	Secondary Screening of Remedial Technologies
Table 12b	Secondary Screening of Supplemental Substrate Delivery and Groundwater Recovery Process Options
Table 13	Major Components of Remedial Alternatives
Table 14	Cost Estimates for Remedial Alternatives
Table 15	Comparison of Remedial Alternatives

## FIGURES

Figure 1a	Site Location Map
Figure 1b	Site Vicinity
Figure 1c	Site Plan
Figure 1d	Site Plan and In Situ Bioremediation Treatment Area
Figure 2a	Cross Section A-A'
Figure 2b	Cross Section B-B'
Figure 3a	A-Zone Water Levels, October 11, 2010
Figure 3b	B1-Zone Water Levels, October 11, 2010
Figure 3c	B2-Zone Water Levels, October 11, 2010
Figure 4a	Concentrations of Key Chemicals of Concern in A-Zone Wells
Figure 4b	Concentrations of Key Chemicals of Concern in B1-Zone Wells
Figure 4c	Concentrations of Key Chemicals of Concern in B2-Zone Wells
Figure 5a	Concentration Trends for A-Zone Monitoring Wells
Figure 5b	Concentration Trends for B1-Zone Monitoring Wells
Figure 5c	Concentration Trends for B2-Zone Monitoring Wells
Figure 6a	TCE and cDCE Concentrations at Upgradient Sites
Figure 6b	Concentration Trends for Selected Monitoring Wells
Figure 6c	Representative Historical Groundwater Fluctuation in the Santa Clara Valley Subbasin

## APPENDICES

Appendix A	Summary of Historical COC Concentrations in Pumping and Monitoring Wells
Appendix B	Simulated Capture Zones Provided in the Second Five-Year Report
Appendix C	Development of Groundwater Risk Based Concentrations for Vapor Intrusion Pathway
Appendix D	Remediation Time-Frame Analysis
Appendix E	Cost Estimates

## TABLE OF CONTENTS (Continued)

### LIST OF ABBREVIATIONS

1,1,1-TCA	1,1,1-trichloroethane
1,1-DCA	1,1-dichloroethane
1,1-DCE	1,1-dichloroethene
1,2-DCB	1,2-dichlorobenzene
AMD	Advanced Micro Devices
ANS	acid neutralization system
ARAR	applicable or relevant and appropriate requirement
bgs	below ground surface
BPHE	baseline public health evaluation
cDCE	cis-1,2-dichloroethene
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	constituent of concern
EPA	Environmental Protection Agency
ESL	ecological screening level
FFS	Focused Feasibility Study
$f_{oc}$	fraction of organic carbon
ft/d	feet (foot) per day
GAC	granular activated carbon
gpm	gallons per minute
GRA	general response action
GWET	groundwater extraction and treatment
HVAC	heating, ventilation and air conditioning
ISB	in situ bioremediation
kg/L	kilograms per liter
$K_{oc}$	organic carbon-to-water partition coefficient
MCL	maximum contamination level
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MNA	monitoring natural attenuation
NCP	National Contingency Plan

## TABLE OF CONTENTS (Continued)

## LIST OF ABBREVIATIONS (Continued)

NPDES	National Pollutant Discharge Elimination System
O&M	operations and maintenance
PCE	tetrachloroethene
PRB	permeable reactive barrier
RAO	remedial action objective
RBC	risk-based concentration
RI/FS	remedial investigation/feasibility study
ROD	Record of Decision
RSL	regional screening level
SVE	soil vapor extraction
TBC	to be considered
TCE	trichloroethene
tDCE	trans-1,2-dichloroethene
TMV	toxicity, mobility, and volume
TOC	total organic carbon
UST	underground storage tank
VC	vinyl chloride
VOC	volatile organic compound
ZVI	zero-valent iron
µg/L	micrograms per liter

## **FOCUSED FEASIBILITY STUDY**

Former 901/902 Thompson Place  
Sunnyvale, California

### **EXECUTIVE SUMMARY**

#### **1.0 INTRODUCTION**

The California Regional Water Quality Control Board, San Francisco Region (the "Water Board") regulates the Former Advanced Micro Devices (AMD) 901/902 Thompson Superfund site (the "site") under Order No. 91-102 (the "Cleanup Order") adopted on June 19, 1991. The U.S. Environmental Protection Agency (U.S. EPA) Region 9 Superfund Division provides technical guidance and support to the Water Board.

In a letter dated November 18, 2010, the Water Board requested that AMD complete a Focused Feasibility Study (FFS) in order to help the Water Board evaluate and select a revised cleanup plan and prepare a revised final site cleanup requirements order. AMEC Geomatrix, Inc. (AMEC), on behalf of AMD, has compiled necessary information and technical analyses, as described in this FFS report, to facilitate the Water Board's decision-making process and accelerate site cleanup. The report is organized in accordance with the U.S. EPA guidance on conducting a feasibility study (U.S. EPA, 1988) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund (U.S. EPA, 1980).

This Executive Summary serves as an overview of the FFS report and is organized as follows: (1) summary of site background, (2) description of groundwater remediation performed since 1983, (3) summary of the extent and magnitude of the constituents of concern (COCs) in groundwater, (4) presentation of the remedial alternatives considered in the FFS, (5) summary of the proposed remedy, and (6) how the proposed remedy satisfies the nine evaluation criteria specified in the U.S. EPA Guidance, EPA/540/G/004.

#### **2.0 SITE BACKGROUND**

The site is located at 901/902 Thompson Place near the intersection of DeGuigne and Stewart Drives in Sunnyvale. The original buildings at the site were vacated by AMD in 1992 and remained vacant until the property was sold to Summit Commercial Properties. Summit is the current owner of the property, and has redeveloped the site for use as a self-storage facility, and has changed the address from 901/902 Thompson Place to 875 East Arques Avenue. Land use in the area is primarily industrial and commercial.

AMD manufactured printed circuit boards and semiconductors at the site from 1969 to 1991. Chemicals historically used by AMD for semiconductor fabrication at the site included solvents

and corrosives. The chemical releases from at two belowground acid neutralization tank vaults at the site were detected and repaired in 1982. The site has undergone several phases of remediation effort since 1983. With respect to unsaturated zone soil, the Water Board has issued a No Further Action letter to indicate the completion of site soil investigation and remedial actions for releases. Groundwater remediation is still ongoing at the site.

### **3.0 GROUNDWATER REMEDIATION PERFORMED SINCE 1983**

The remedy approved in the Cleanup Order issued by the Water Board in 1991 consists of a groundwater extraction and treatment (GWET) system, groundwater monitoring, and institutional controls. The GWET system began operation in 1983 with three extraction wells, was expanded to a total of eight extraction wells in 1993, and continued operating through 2002.

Although concentrations of VOCs associated with onsite releases had decreased as a result of the GWET operation, but the rate of VOC concentration reduction was marginal and VOC concentrations remained considerably above cleanup standards during the final ten years of the GWET operation. It is believed that VOCs stored in the low permeability zones of the aquifer system cannot be readily flushed out, and thus prolong the cleanup time. Because of declining effectiveness of the selected remedy, a new remedy, in situ bioremediation, was tested and implemented to accelerate site cleanup, starting from 2002.

#### **3.1 Current Magnitude and Extent of Concentrations Compared to Cleanup Standards and Screening Levels**

Impacted groundwater associated with the past site-related activities is primarily restricted to the north portion of the site and does not underlie any residential areas. Concentrations of volatile organic compounds (VOCs) have decreased over time. Out of the ten constituents of concern listed in the Cleanup Order issued by the Water Board in 1991, the concentrations of four VOCs (1,1-dichloroethane, 1,1,1-trichloroethane, 1,1,2-trichloro-1,2,2-trifluoromethane, and 1,2-dichlorobenzene) in groundwater have been remediated to below their respective cleanup standards. Concentrations of 1,1-dichloroethene and tetrachloroethene slightly exceed their cleanup standards in only one monitoring well. The concentrations of trichloroethene (TCE), although still being significantly above its cleanup standard, have decreased considerably because of the full-scale in situ bioremediation implemented at the site since 2005. For the other three VOCs, cis-1,2-dichloroethene (cDCE), trans-1,2-dichloroethene (tDCE), and vinyl chloride (VC), the concentrations are elevated because in situ bioremediation promotes the transformation of TCE to these intermediate breakdown products. Eventually, these VOC can be breakdown by bacteria to carbon dioxide and chloride, which are harmless compounds that occur naturally in groundwater.

The most recent results of the VOC concentrations in shallow groundwater indicate that only **VC concentrations at certain locations exceed the Water Board's Environmental Screening**



Level (ESLs) for industrial and commercial land use only. The vapor intrusion concern for VC is insignificant because any potential for vapor migration into the building would be mitigated by the extensive HVAC system installed and operated at the current site building, as described in the Third Five-Year Review by the Water Board and the U. S. EPA in 2009.

#### **4.0 ALTERNATIVES CONSIDERED IN THE FOCUSED FEASIBILITY STUDY (FFS)**

The remedial technologies and process options were screened to obtain suitable components for remedial alternative development. The remedial alternatives that have been identified for evaluation in the FFS are presented below.

- Alternative 1: No Further Action.
- Alternative 2: Groundwater extraction and treatment.
- Alternative 3: Monitored natural attenuation in the A zone and groundwater extraction and treatment in the B zones.
- Alternative 4: In situ bioremediation and monitored natural attenuation.
- Alternative 5: Permeable reactive barrier.

Alternative 1 is required by the regulation, serving as a baseline for comparative evaluation among alternatives. Alternative 2 is the remedy approved in the 1991 Cleanup Order. Alternative 3 is a modification of Alternative 2. It requires less groundwater extraction to hydraulically contain and remove site-related COCs than Alternative 2. Alternative 4 is similar to the in situ bioremediation remedy tested and implemented at the site since 2002. The alternative includes injection of carbohydrate solution or slow-releasing organic substrates to stimulate microbial activity and enhance VOC degradation and utilization of intrinsic microbial activity to polish impacted groundwater when concentrations of site-related VOCs decrease to upgradient groundwater conditions. Alternative 5 is to place reactive materials at the site boundary to intercept and treat impact groundwater in situ.

The alternatives considered in the FFS were evaluated following the criteria set forth in the **National contingency Plan and U.S. EPA's guidance. A comparative analysis of these alternatives is provided in Table ES-1.**

#### **5.0 PROPOSED ALTERNATIVE**

In situ bioremediation coupled with monitored natural attenuation is proposed to be the revised remedy for the site. This alternative has greatest potential of accelerating site cleanup, and it outperforms other alternatives in terms of short-term and long-term effectiveness and permanence.

## **6.0 HOW THE PROPOSED ALTERNATIVE ADDRESSES THE NINE EVALUATION CRITERIA IN THE GUIDANCE**

The proposed alternative fully satisfies the nine evaluation criteria in the U.S. EPA guidance as described below:

1. Overall Protection of Human Health and Environment: The proposed alternative can effectively reduce VOC concentrations and mass by stimulating biodegradation and hydraulic flushing, thereby protecting human health and preventing offsite migration of VOCs.
2. Compliance of Applicable or Relevant and Appropriate Requirements (ARARs): The proposed alternative can promote in situ destruction of VOCs and is able to reduce VOC concentrations to meet vapor intrusion screening levels and cleanup standards for site-related VOCs.
3. Long-Term Effectiveness and Permanence: Biodegradation of VOCs is an irreversible process, and thus it satisfies the permanence criterion. Based on the site data collected so far, the proposed alternative can also effectively reduce the toxicity, mobility, and volume of site-related VOCs.
4. Reduction in Toxicity, Mobility, and Volume: The proposed alternative can reduce the extent and concentrations of VOCs in site groundwater simultaneously and effectively.
5. Short-Term Effectiveness: implementation of the proposed remedy is expected to result in negligible exposure of site-related VOCs to on-site construction worker and the community because VOC concentrations in aquifer material are in general low and adequate measures are available to mitigate exposure. Compared with other alternatives, the proposed remedy is expected to restore the site to ambient groundwater conditions in a shortest time frame.
6. Implementability: In situ bioremediation has been implemented at the site. Service, materials, and regulatory approvals and permits for expansion of the present ISB system are expected to be readily obtainable.
7. Cost: The proposed alternative is most cost effective among the alternatives evaluated except for the No Further Action alternative. This is because in situ bioremediation is much more effective in remediating VOCs in the low permeability zones.
8. State Acceptance: in situ bioremediation and monitored natural attenuation have been widely used to treat VOC-impacted groundwater at numerous nearby sites. As long as injected substrates comply with existing regulations, there is no particular concern regarding this technology.
9. Community Acceptance: The community is likely to accept this remedy because it can accelerate site cleanup and does not increase exposure of site-related VOCs to the community.

## 7.0 CONCLUSIONS

The FFS recommends in situ bioremediation and monitored natural attenuation because it more fully satisfies the threshold criteria (overall protection of human health and the environment; compliance with ARARs) in comparison to the other alternatives. Implementation of this remedy consists of the following components: (1) substrate addition using groundwater recirculation and direct injection to stimulate biodegradation, (2) groundwater recirculation for hydraulic control, and (3) monitored natural attenuation when VOC concentrations resemble upgradient groundwater conditions.

With regard to substrate injection, the trade-off between recirculation and direct injection is the longevity and mobility of substrate. Soluble substrate is ideal for recirculation because it is easy to distribute in the transmissive zones; in contrast, direct injection is more suitable for slow-releasing substrate, which promotes microbial activity over a long period of time and permits substrate diffusion into the low-permeability zones.

The time required to achieve the cleanup standards may be prolonged because of the upgradient, offsite impacted groundwater. When VOC concentrations in site groundwater resemble upgradient groundwater conditions, Monitored natural attenuation will be used to manage impacted groundwater. Additional investigation of impacted groundwater at the southern site boundary will help define the trend and extent of VOCs from the upgradient sources.

In summary, it is recommended that the remedy be adopted as the revised final remedy for the site. In comparison with the original remedy, the revised remedy will further accelerate site cleanup and will also provide better protection of human health and the environment.

TABLE ES-1  
COMPARISON OF REMEDIAL ALTERNATIVES  
Former 901/902 Thompson Place  
Sunnyvale, California

Feasibility Evaluation Criteria												
	Overall Protection of Human Health and Environment			Compliance with ARARs			Long-Term Effectiveness and Permanence	Reduction in Toxicity, Mobility, and Volume	Short-Term Effectiveness	Implementability		Cost
Remedial Alternative	Prevents Migration to Downgradient Area	Protection Against the Use of GW	Reduces Exposure of Potential Vapor Intrusion	Cleanup Standards for Groundwater	Discharge and Injection Limits	Time to Reach Upgradient GW Conditions	Optimizes Removal or Reduction of COCs to Reduce Long-Term Reliance on O&M	COC Distribution and Concentration	Protection During Construction and Implementation Period	Remedial Facilities in Place	Engineering Services, Materials, Approvals, and Permits	Estimated Total Costs
RA-1: No Further Action	No, impacted GW moves downgradient.	Institutional controls will be implemented at the site to prevent the use of GW before it reaches the cleanup standards.	Natural attenuation processes are responsible for the concentration decrease in shallow GW.	For all RAs, the ability to meet the GW cleanup standards depends on the off-site upgradient GW quality.	NA	RA-1 does not accelerate the time to reach the upgradient GW conditions.	RA-1 does not actively reduce or remove COCs from impacted GW.	RA-1 cannot effectively reduce the extent of COCs and concentrations in site GW.	The risk associated with site-related COCs has been greatly reduced through various remedial actions for the past three decades. The additional risk associated with construction and implementation of any of the RAs is expected to be minimal and manageable.	NA	Engineering service, materials, and regulatory approvals and permits for construction of a new installation or expansion of the existing extraction and ISB systems are expected to be readily obtainable.	\$0
RA-2: GWET	Yes, hydraulic control will prevent COCs from moving off site.		Enhanced flushing through GW extraction will help reduce concentrations in shallow GW to some extent.		Discharge of treated water will comply with requirements specified in the NPDES permit.	GW extraction enhances the desorption of COCs from the low-permeability zones, thereby reducing the time to reach the upgradient GW conditions.	RA-2 and RA-3 moderately reduce the time to remediate the site. They are not as effective as RA-4 because they do not promote COC destruction in the low-permeability zones.	GW extraction can reduce the extent and concentrations of COCs in site GW, but its effectiveness is limited by the desorption of COCs from the low-permeability zones.		Yes	\$1,530,000	
RA-3: MNA for A Zone GWET for B Zones	Yes, hydraulic control will prevent COCs from moving off site in the B zones. Small mass flux of COCs leaving from the A zone is expected due to intrinsic microbial activity and pumping in the B zones.		Similar to RA-1.							Yes	\$1,359,000	
RA-4: ISB and MNA	Yes, GW recirculation and microbial degradation will prevent COCs from moving off site. When the upgradient GW conditions prevail at the site, MNA will be used to polish GW quality.		RA-4 optimizes the removal of COC mass by enhancing biodegradation and flushing in shallow GW through substrate addition and GW circulation, reducing both exposure concentrations and time frame.		Injected nutrient solution will comply with the criteria established by the Water Board.	ISB can achieve upgradient GW conditions in the shortest time frame since it is the most effective RA to remove COCs from low-permeability zones.	RA-4 optimizes the removal of COC mass in the low-permeability zones and is capable of significantly reducing the time to reach upgradient GW conditions.	ISB will reduce the extent and concentration of COCs in site GW concurrently and effectively.		Yes	\$947,000	
RA-5: PRB	Yes, COCs will be destroyed by the PRB.		Similar to RA-1. Significant COC destruction only occurs within the PRB.							NA	Similar to RA-1.	Similar to RA-1.

Abbreviations

ARARs = applicable or relevant and appropriate requirements; COC = constituent of concern; GW = groundwater; GWET = groundwater extraction and treatment; ISB = in situ bioremediation; MNA = monitored natural attenuation; NA = not applicable; NPDES = national pollutant discharge elimination system; O&M = operations and maintenance; RA = remedial alternative; PRB = permeable reactive barrier

## **FOCUSED FEASIBILITY STUDY**

### **Former 901/902 Thompson Place**

### **Sunnyvale, California**

#### **1.0 INTRODUCTION**

##### **1.1 PURPOSE AND ORGANIZATION OF REPORT**

The California Regional Water Quality Control Board, San Francisco Region (the "Water Board") regulates the Former Advanced Micro Devices (AMD) 901/902 Thompson Place Superfund site (the "site") under Order No. 91-102 (the "Order") adopted on June 19, 1991. The U.S. Environmental Protection Agency (U.S. EPA) Region 9 Superfund Division provides technical guidance and support to the Water Board.

In a letter dated November 18, 2010, the Water Board requested that AMD complete a Focused Feasibility Study (FFS) in order to help the Water Board evaluate and select a revised cleanup plan and prepare a revised final site cleanup requirements order. AMEC Geomatrix, Inc. (AMEC), on behalf of AMD, has compiled the relevant information and technical analyses, as described in this FFS report, to facilitate the **Water Board's decision-making** process and document a path toward accelerated site cleanup. The report is organized in accordance with the U.S. EPA guidance on conducting a feasibility study (U.S. EPA, 1988) under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), commonly known as Superfund (U.S. EPA, 1980). The organization of the report is described below.

Section 1.0 of this report summarizes the information about the site, including the site background, physical characteristics of the aquifer system beneath the site, nature and extent of chemical constituents in the subsurface, risks of the site to human health and potential ecological receptors, and effectiveness of site cleanup remedies implemented to date. Section 2.0 presents Remedial Action Objectives (RAOs) and cleanup standards that have been developed for the site. Section 3.0 documents the screening of remedial technologies. Section 4.0 presents the remedial alternatives to be considered based on the results of technology screening. Section 5.0 provides a detailed analysis of remedial alternatives. Section 6.0 presents a comparative analysis of the alternatives. Section 7.0 provides the recommended remedial alternatives for the site.

##### **1.2 SITE LOCATION AND CURRENT USE**

The site is located at 901/902 Thompson Place, south of Highway 101, in Sunnyvale, Santa Clara County, California (Figure 1a). AMD sold the property to Summit Commercial Properties in 2005 who redeveloped the site for use as a self-storage facility in 2007, at which time the address was changed from 901/902 Thompson Place to 875 East Arques Avenue. The site is

in a light industrial and commercial area dominated by the electronics industry that is known as the Silicon Valley, which is a portion of Santa Clara Valley. Most buildings in the vicinity of the site are low-rise building developments containing office space and research and development facilities. The site boundaries as defined in the Order are shown on Figure 1b.

A network of 21 monitoring wells and 21 current or former extraction wells exists on the site. Six offsite AMD monitoring wells and 17 other non-AMD monitoring wells exist in the area immediately surrounding the site. Well locations are included on Figure 1c. A site plan focusing on the in situ bioremediation (ISB) program area is shown on Figure 1d.

Because chlorinated solvents were widely used by business entities in the vicinity of the site in the past and because no adequate disposal methods were in place at that time, many sources of chlorinated solvents have been found to impact regional groundwater. The sites near the former 901/902 Thompson Place facility include (1) the adjacent Philips site in the west; (2) the downgradient TRW and AMD 915 sites; (3) the upgradient sites in the south or southwest, consisting of the ICORE International, Philips Semiconductor (Kifer), Royal Auto Body, Magnetics, Pilkington Barnes Hind, and Mohawk Laboratories sites; (4) the former Fairchild and former United Technologies sites in the southeast. Figure 1b shows the locations of these nearby sites. Of these identified sites, the six upgradient sites have the greatest potential to impact groundwater beneath the former AMD 901/902 Thompson Place site.

### 1.3 SITE OPERATION HISTORY AND CHRONOLOGY

AMD operated a facility to design and fabricate semiconductor devices between 1969 and 1992 (Arcadis, 2001). Two belowground acid neutralization system (ANS) tank vaults were located at the northern and southern ends of the former 901 and 902 Thompson Place buildings, respectively (Arcadis, 2001). Both of the ANS tanks were constructed of coated concrete, had capacities of 2,000 gallons or less (Arcadis, 2001), and were used to contain acidic industrial wastewater that was neutralized by adding caustics before discharging to the sanitary sewer (Parsons ES, 1996).

Chemicals historically used by AMD for semiconductor fabrication at the site included solvents and corrosives (Engineering Science, 1988). Records of chemical use prior to 1980 are not available; however, it has been inferred by others that TCE was used on site between 1969 and 1979 (Engineering Science, 1988). The primary on-site source of trichloroethene (TCE) in groundwater and soil beneath the site appears to have been leakage of volatile organic compounds (VOCs) either from cracks in the ANS tanks that developed over time or from the movement of VOCs through the tanks' concrete walls (Engineering Science, 1988). The two ANS tanks were removed between 1983 and 1984 and replaced by two sets of three underground storage tanks (USTs) and associated vaulted containment systems (Arcadis, 2001). As of 1980, the majority of the solvent waste generated by site activities was collected

and stored in an aboveground storage tank (Arcadis, 2001). Hazardous waste materials were containerized in 55-gallon drums in a hazardous material storage area.

The buildings were vacated by AMD in 1992 (Engineering Science, 1992) and remained vacant until the property was sold to Summit and redeveloped in 2007. Soil and groundwater remediation was implemented at the site in 1983 after soil and groundwater sampling indicated the presence of VOCs in the subsurface in 1982. A more detailed chronology of the site is provided in Table 1.

#### **1.4 SITE CHARACTERIZATION**

The site has undergone several phases of investigation since the initiation of groundwater monitoring in 1982. To facilitate site characterization, remedial actions, and performance monitoring, a network of 62 former and current monitoring and/or extraction wells has been installed. The specifications of these wells are summarized in Table 2.

This section presents the site hydrogeology and the nature and extent of constituents of concern (COCs) in both site soil and site groundwater.

##### **1.4.1 Site Hydrogeology**

The site is located in the central portion of Santa Clara Valley of the Coast Range physiographic province, an area characterized by north-south-trending valleys and mountains. Specifically, the site is located within the San Jose sub-area of the South Bay groundwater basin. This area is characterized by a thick alluvial sequence underlain by sediments of the Santa Clara Formation (DWR, 1967). The alluvium generally is considered to be water-bearing, with coarse-grained alluvial deposits representing ancestral stream channels and levee deposits, conveying groundwater from the forebay regions south and west of the site near the Santa Cruz Mountains, toward San Francisco Bay (Helley, et al., 1979). Sequential depositional processes in the San Francisco region over time have resulted in an alluvial environment characterized by irregular interbedding and interfingering of fine and coarse material. Individual deposits may show highly variable thickness and lateral extent (Helley et al., 1979). This depositional environment has resulted in a high degree of heterogeneity with respect to hydrogeologic conditions beneath the site.

##### **1.4.1.1 Hydrostratigraphic Zones**

The site hydrostratigraphy is described by Engineering Science (1986) as a sequence of coarse-grained sediments separated primarily by silty clay. From shallow to deep, the primary hydrostratigraphic zones are described as follows:

1. The A zone is an approximately 5-foot-thick, relatively continuous sandy layer typically encountered between 7 and 20 feet below ground surface (bgs). The direction of the lateral hydraulic gradient generally is north toward San Francisco Bay.

2. The B1 zone comprises multiple vertically thin (i.e. less than three feet thick), lenticular sand and gravel intervals typically encountered between 22 and 40 feet bgs.
3. The B2 zone is an approximately 4-foot-thick discontinuous sequence of sand and gravel lenses typically encountered between 45 and 65 feet bgs.
4. The B3 zone is a system of two sandy layers approximately 1 and 4 feet thick, respectively, that is encountered between approximately 70 and 80 feet bgs.

The depth intervals designated for each of the zones are not consistent among many of the early reports on site hydrogeology; different interpretations of depth intervals for various zones likely occurred because of the complex nature of the alluvial system beneath the site, in which sand zones comprise elongated, channel-type deposits that can occur at various depths and widths, with a meandering three-dimensional configuration, rather than a series of horizontal, continuous layers. Nonetheless, A-zone wells are generally screened from 10 to 25 feet bgs; B1-zone wells from 25 to 45 feet bgs; B2-zone wells from 45 to 55 feet bgs; and the one B3-zone well (35-DDD) from 70 to 80 feet bgs (Engineering Science, 1982).

The complex features of site hydrogeology are partially captured on Figures 2a and 2b. These cross sections cover the area near the former 901 Thompson Place building and contain additional lithologic and chemical information obtained during the full-scale ISB implementation, thereby allowing better delineation of the hydrostratigraphic zones. Interpretations of site geologic cross sections and the results of aquifer testing performed at the site indicate that coarse-grained sediments in the aquifer are likely to form continuous preferential groundwater flow paths. The remaining portion of the aquifer contains predominantly silt, clay, and finer-grained sediments and apparently decreases the hydraulic communication between various hydrostratigraphic zones.

#### **1.4.1.2 Groundwater Flow**

The depth of the uppermost groundwater surface typically is encountered at approximately 10 feet bgs and generally occurs under confined conditions. Based on the water level data collected in 2010 at the site, the groundwater flow direction beneath the site is generally to the north-northeast in all aquifers. This coincides with the historical and regional groundwater directions under natural conditions (U.S. EPA, 1991). The 2010 water level results for the A1, B1, and B2 zones in the vicinity of the site are shown on Figures 3a through 3c. In the vicinity of the former building, the horizontal gradients in the A zone range from 0.005 (near 29-S) to 0.0125 (near 16-S); the horizontal gradients in the B1 and B2 zones are approximately 0.008. It is noted that, before the ISB system was implemented, aggressive groundwater extraction had been implemented for containment of VOC-affected groundwater, and this had resulted in large variations in historical groundwater flow directions in the vicinity of the site (HLA, 1991; Arcadis, 2001).



The regional vertical hydraulic gradient has previously been documented to be upward under non-pumping conditions (U.S. EPA, 1991). Groundwater elevations recorded in 2010 at locations where water levels were measured for wells representing multiple depth intervals indicate that the direction of calculated vertical hydraulic gradients was generally upward at the site. The upward vertical gradients were calculated for well pairs 23-S and 23-D, 27-S and 27-D, 27-D and 27-DD, 28-S and 28-D, 29-S and 29-D, 36-S and 36-D, and 36-D and 36-DD. A downward vertical gradient value was calculated for the well pair 16-S and 16-D.

#### **1.4.1.3 Aquifer Properties**

Quantitative data on the aquifer properties, including hydraulic conductivity, organic carbon content, bulk density, and effective porosity for solute transport, are essential to the understanding of groundwater flow hydraulics and solute transport processes in the aquifer system. Values of hydraulic conductivity and storativity obtained through early field aquifer testing at the site were documented by Engineering Science (1986). These hydraulic parameters are the basis of two groundwater models built for assessing the effectiveness of the site groundwater extraction system (Engineering Science, 1986; Arcadis, 2001).

The values of hydraulic conductivity in the A zone range from 0.8 to 30 feet per day (ft/d), with a geometric mean of 12.6 ft/d. The values of hydraulic conductivity in the B1 zone range from 0.8 to 176.6 ft/d, with a geometric mean of 42.3 ft/d. The values of hydraulic conductivity in the B2 zone range from 11.28 to 27.9 ft/d, with a geometric mean of 17.7 ft/d.

The value representative of the fraction of organic carbon ( $f_{oc}$ ) at the site is considered to be 0.2 percent. The estimate is based on soil analyses performed for the Mohawk Laboratories site (Source Group, 2003), located approximately 3,000 feet south of the site. This value is considered to be representative because the Mohawk site is relatively close and appears to be underlain by a similar aquifer system.

As part of the feasibility study performed in 1991 (HLA, 1991), a one-dimensional batch-flushing model was used to estimate cleanup times for the A zone and combined B zones. The values of soil bulk density, effective porosity, and total porosity, as input parameters for the batch-flushing model, were based on a hydrogeologic investigation at the National Semiconductor Corporation facility located  $\frac{3}{4}$  mile southeast of the site. The values presented therein (bulk density = 1.48 kilograms per liter (kg/L); total porosity = 0.36; effective porosity = 0.2) resemble the fine-grained portion of the aquifer. For the coarse-grained zones, the values from a solute transport modeling study for the nearby Mohawk site (bulk density = 1.9 kg/L; effective porosity = 0.3) may be more appropriate (Source Group, 2003). Aquifer parameters are summarized in Table 3.

#### **1.4.2 Nature and Extent of Constituents of Concern in Soil**

Initial investigation at the site began in 1982 with a subsurface investigation targeting the acid neutralization system near the former AMD 901 Thompson Place building (Water Board, 2009a). The subsequent investigation conducted in the vicinity of both neutralization tanks at the site found soils impacted by VOCs. These impacted soils were considered as point sources for VOC-affected groundwater.

Soil excavations were completed by AMD in 1983, 1984, and 1992 (Parson ES, 1995; Arcadis, 2001). The Water Board has reviewed the relevant soil and groundwater sampling results for VOCs and issued a No Further Action letter, dated May 14, 2008, to confirm the completion of site investigation and remedial actions for releases with respect to unsaturated zone soil at the site (Water Board, 2008a). This decision was also recorded in the Third Five-Year Review issued in September 2009. Shallow soil at the site is no longer considered a source for groundwater impacts (Water Board, 2009a).

#### **1.4.3 Nature and Extent of COCs in Groundwater**

The primary sources of groundwater contamination at the site were likely the neutralization tanks and storage tanks. The maximum historical TCE concentration found in groundwater was 110,000 µg/L at the well 28-S, located near the neutralization tank adjacent to the former 901 Thompson Place building. The implementation of the groundwater extraction and treatment (GWET) system and ongoing in situ biological treatment since 2002 has greatly reduced the TCE concentrations in the treatment area to less than 5 µg/L. The following subsections provide (1) a definition of COCs in groundwater at the site, (2) current distributions of COCs in each hydrostratigraphic zone, (3) an evaluation of historical COC concentration trends in groundwater, and (4) an assessment of COC concentrations in site groundwater samples.

#### **1.4.4 Constituents of Concern**

As part of the baseline public health evaluation (BPHE; Clement, 1990), the complete list of chemicals detected in environmental media was evaluated and a subset of those chemicals was selected to represent the COCs. Ten COCs for groundwater were selected for the comingled groundwater plume that resulted from the AMD, Philips, and TRW sites, as follows:

- 1,2-dichlorobenzene (1,2-DCB)
- 1,1-dichloroethane (1,1-DCA)
- 1,1-dichloroethene (1,1-DCE)
- cis-1,2-dichloroethene (cDCE)
- trans-1,2-dichloroethene (tDCE)
- Freon 113

- tetrachloroethene (PCE)
- 1,1,1-trichloroethane (1,1,1-TCA)
- trichloroethene (TCE)
- vinyl chloride (VC)

All the compounds above have been detected at the site, however, the major COCs are TCE, cDCE and vinyl chloride, whereas the others are much lower in concentration. The COC concentrations in groundwater detected at the site in October 2010 are summarized in Table 4.

#### **1.4.5 Current COC Distributions in Groundwater**

The interpretation of current COC distribution in groundwater is based on groundwater sampling results reported in the *2010 Combined Annual Groundwater Monitoring and Annual In Situ Bioremediation Program Report* (AMEC, 2011). Figures 4a through 4c show the concentrations of primary COCs in groundwater, including TCE, cDCE, VC, and tDCE, in the A, B1, and B2 zones.

Concentrations of primary COCs detected in groundwater samples from most A-zone, B1-zone, and B2-zone monitoring wells during the 2010 monitoring event generally were stable or decreased compared with the chemical results obtained in 2009, suggesting that passive destruction of COCs due to ISB processes is continuing. At some locations, rebound in concentrations was observed, indicating that microbial dechlorinating activity gradually decreased in parts of the ISB treatment zone. AMEC is currently planning additional substrate injection at the site to enhance the ISB performance.

The COC concentrations reported in 2010 are generally consistent with a long-term decreasing trend, which was accelerated by the ISB program (AMEC, 2008). The key COC concentrations in the A, B1, and B2 zones are shown on Figures 4a through 4c.

##### **1.4.5.1 COC Concentrations in the ISB Treatment Area**

In the A zone, the TCE concentrations reported in 2010 groundwater samples were generally low (<10 µg/L) within the property boundary except at the location of 27-S. The cDCE concentrations are below or near 10 µg/L in the core ISB treatment area. The highest cDCE concentration observed in the A zone was 350 µg/L at 23-S in 2010. The high cDCE concentration found at this well coincides with a low total organic carbon (TOC) concentration (2.7 mg/L), suggesting that insufficient substrate leads to incomplete cDCE transformation. Higher concentrations of VC were found in the ISB treatment area (e.g., 850 µg/L at X2A and 77 µg/L at 28-S), also indicating that additional substrate is required to support complete transformation of VC to ethene.

In the B1 zone, the COC concentrations ranged from 0.6 µg/L (DW-1) to 240 µg/L (X1-B) for TCE; from 1.2 µg/L (DW-1) to 6,800 µg/L (PMW-2-1) for cDCE; and from 3.1 µg/L (DW-1) to 1,800 µg/L (PMW-2-1) for VC in the ISB treatment area. It is noted that COC concentrations at the PMW-2 location have been always high. It is likely that the wells (PMW-2-1 and PMW-2-2) installed at this location may be screened in a fine grained interval, thereby limiting substrate delivery to its vicinity. The COC levels in the B zone are generally higher than those observed in the A zone. The elevated cDCE and VC concentrations in the B zone indicate the presence of dechlorinating bacteria and insufficient substrate to complete transformation of chlorinated ethenes. Effective delivery of additional substrates is expected to promote reductive transformation and reduce COC concentrations to the levels observed at DW-1.

For the B2 zone, there is only one monitoring well (PMW-2-3) in the ISB treatment area. The key COC concentrations are 260 µg/L for TCE, 220 µg/L for cDCE, and 21 µg/L for VC. These levels are consistent with the concentrations observed since 2005.

#### **1.4.5.2 COC Concentrations in the Area Upgradient of the ISB Treatment Area**

The on-site monitoring wells upgradient of the ISB treatment area consist of the following: 15-S, 27-S, 27-D, 27-DD, 29-S, 29-D, 52-D, and 53-D. The concentration of TCE in the samples collected from the upgradient wells is generally greater than cDCE; the concentrations of cDCE remained low (close to or below the cleanup goal of 6 µg/L) in most of the upgradient wells.

In groundwater samples collected during the 2010 annual groundwater monitoring event, concentrations of TCE in individual hydrostratigraphic zones ranged from 11 to 300 µg/L in the A zone; 6.9 to 110 µg/L in the B1 zone; and 59 µg/L in the B2 zone. The concentrations of cDCE in individual hydrostratigraphic zones range from 9.3 to 79 µg/L in the A zone; non-detect (<0.5 µg/L) to 1.9 µg/L in the B1 zone; and 3.9 µg/L in the B2 zone. VC was not detected in the upgradient monitoring wells. It is noted that the TCE and cDCE concentrations at 27-S, 27-D, and 27-DD are significantly higher than those at other upgradient wells. These wells are likely affected by off-site upgradient non-AMD sources (AMEC, 2011).

#### **1.4.5.3 COC Concentrations in the Downgradient Off-Site Monitoring Wells**

For downgradient off-site wells (36-S, 36-D, 36-DD, and 37-S), COC concentrations detected in 2010 were generally similar to or lower than 2009 concentrations. One exception to this was 36-D, in which reported TCE concentrations (47 µg/L) were significantly higher than in 2009 (19 µg/L). TCE was reported at higher concentrations than cDCE in the shallow (A-zone) wells, 36-S and 37-S. Concentrations of cDCE detected in shallow groundwater were close to or below the cleanup goal (6 µg/L). For wells 36-D (B1 zone) and 26-DD (B2 zone), TCE and cDCE concentrations were all below 50 µg/L. VC was detected, but at a concentration below 3 µg/L.

#### **1.4.5.4 COC Concentrations in the B3 Zone**

Well 35-DDD has been used to monitor the COC concentrations in the B3 zone since 1985. No COCs were detected from the groundwater sample collected from this well in 2010. It is likely that the upward groundwater gradient between the B3 and B2 zones minimizes downward spread of COCs.

#### **1.4.6 Historical Concentration Trends in Site Monitoring Wells**

A discussion of historical concentrations in groundwater is presented in this subsection, with a focus on the change in COC concentrations over time. In Section 1.6, below, the historical concentration data are used to help evaluate the effectiveness of two remedial actions, GWET and ISB that have been implemented at the site. Figures 4a through 4c summarize the historical concentration data for key COCs during the period from the onset of ISB treatment in 2005 through 2010. Figures 5a through 5c illustrate the trends of TCE and cDCE concentrations since 1982. Appendix A provides tabulated historical concentration data for TCE and cDCE.

##### **1.4.6.1 ISB Treatment Period (2005–2010)**

For shallow groundwater (A zone), TCE concentrations observed in 2010 were lower than those detected at the same locations before ISB treatment began, indicating the successful application of the alternative groundwater cleanup strategy towards expediting groundwater cleanup (Figure 4a). The extent of TCE concentration reduction for some wells in the B1 and B2 zones, however, is less pronounced (Figures 4b and 4c). At some locations (e.g., X1B and 23-D), rebound in concentrations was observed, indicating that microbial dechlorinating activity gradually decreased in parts of the treatment zone.

By comparing the concentrations from before the onset of ISB with those from 18 months after entering into the passive mode (data collected in 2010), the concentration trends were divided into various categories for individual zones, as follows:

- A zone: (1) At DW-2, the concentrations of all chlorinated ethenes decreased to the levels below the cleanup goals; (2) at 16-S and 22-S, the concentrations of all chlorinated ethenes decreased; (3) at 23-S, 28-S, 28-MW, and X2A, the TCE concentrations decreased but the total concentrations of cDCE and VC increased; and (4) at 27-S, located upgradient of the ISB treatment zone, TCE and VC concentrations remained generally stable.
- B1 zone: (1) At DW-1, the concentrations of all chlorinated ethenes decreased to the levels below or close to the cleanup goals; (2) at 16-D, DW-7, X1B, X2B1, and 28-D, the TCE concentrations decreased, but the total concentrations of cDCE and VC increased; (3) at 23-D, the TCE, cDCE, and VC concentrations increased; (4) at PMW-2-1, the TCE, cDCE, and VC concentrations remained stable; and (5) at 27-D, located upgradient of the ISB treatment zone, TCE and VC concentrations remained generally stable.

- B2 Zone: (1) At PMW-2-3 (in the ISB area) and 27-DD (upgradient of the ISB area), concentration trends remained generally stable; and (2) at 22-D, the TCE concentrations increased while the cDCE and VC concentrations decreased.

#### **1.4.6.2 Groundwater Extraction and Treatment Period (1983–2002)**

The GWET system at the site was comprised of eight extraction wells (DW-1 through DW-8) and was operated continuously from 1983 through 2002. Operation of the GWET system was discontinued to facilitate the ISB pilot test in December 2002. The concentration trends for each hydrostratigraphic zone, based primarily on the historical trends of key COC concentrations (TCE, cDCE and VC) in groundwater from 1982 through 2002 (Figures 5a through 5c), are as follows:

- A zone: (1) For 27-S, 15-S, and 29-S, located in the area upgradient of and away from the extraction wells, TCE concentrations decreased by no more than one order of magnitude over 20 years, and cDCE concentrations remained stable or increased; (2) for 22-S, 23-S, 28-S, and 16-S, located in the area under the immediate influence of extraction wells, TCE and cDCE concentrations decreased by two or three orders of magnitude; (3) for 36-S located approximately 300 feet northeast (downgradient) of the GWET system, TCE concentrations decreased by two orders of magnitude and cDCE concentrations increased; (4) for 37-S, located approximately 300 feet northwest (downgradient) of the GWET system, TCE and cDCE concentrations decreased by one order of magnitude.
- B1 zone: (1) For 27-D, 29-D, and 53-D, located in the area upgradient of and away from the extraction wells, TCE concentrations either decreased by one order of magnitude or remained generally stable, and cDCE concentrations did not decrease substantially; (2) for 16-D, 23-D, 28-D, and 52-D, located in the area under the immediate influence of the extraction wells, TCE concentrations decreased by approximately two orders of magnitude and cDCE concentrations decreased by over one order of magnitude; (3) for 36-D, located approximately 300 feet northeast (downgradient) of the GWET system, TCE concentrations decreased by approximately one order of magnitude and cDCE concentrations increased.
- B2 zone: (1) For 27-DD, located in the area upgradient of and away from the extraction wells, TCE concentrations remained approximately stable and cDCE concentrations increased slightly; (2) for 22-DD, located in the area under the immediate influence of the extraction wells, TCE and cDCE concentrations decreased only slightly; (3) for 36-DD, located approximately 300 feet northeast (downgradient) of the GWET system, TCE concentrations remained approximately stable and cDCE concentrations increased slightly.
- B3 zone: Well 35-DDD is the only well installed in the B3-zone. TCE and cDCE concentrations found at this well were either below detection limits or considerably below the cleanup goals. The upward groundwater gradient observed between the B2 and B3 zones probably prevents the spread COCs into this zone.

#### 1.4.7 Ambient COC Concentrations in Groundwater

Because the site is located in an industrial area where chlorinated solvents were used extensively in the past, ambient groundwater in this region is impacted with various levels of chlorinated ethenes. According to the modeling study on the TCE and cDCE plumes originating from the nearby Mohawk Laboratories site (Source Group, 2003), those plumes can elongate between 3,000 and 4,000 feet in 20 years, assuming moderate transformation kinetics for TCE (half-life = 2.4 years) and cDCE (half-life = 1.7 to 10 years) in the aquifer system. Therefore, groundwater quality beneath the site is expected to be affected by upgradient contaminated sites.

It is challenging to precisely define historical groundwater flow directions in the vicinity of the site because of highly heterogeneous aquifer conditions, variable historical pumping activities at nearby sites, and the lack of sufficient monitoring wells and historical potentiometric data. To overcome these data gaps and to establish a representative long-term groundwater flow direction, an approach was developed that was based on the cDCE plume originating from the Mohawk Laboratories site that spans over 4,000 feet (Source Group, 2003; Water Board, 2010b). The shape and extent of this long plume represents the collective and long-term influences of natural and artificial hydrogeologic variations in the area (Figure 6a). The apparent representative long-term regional flow direction is approximately north-northeast.

A search on the GeoTracker database maintained by the Water Board indicates that PCE, TCE, and cDCE sources were found at several upgradient locations within approximately 3,000 feet of the site. Tables 5a and 5b briefly summarize the background of these sites as well as the historical and recent groundwater quality in shallow groundwater. Figure 6a shows the locations of these upgradient sources.

The historical maximum concentrations reported for these sites (Table 5a) indicate that the strength and extent of these upgradient sources are considered to be small or moderate in comparison with the Mohawk source. However, judging from the long time lapses between the onset of facilities operation and the occurrence of groundwater monitoring or extraction at the ICORE International, Royal Auto Body, and Magnetics sites, it is likely that a significant portion of chlorinated ethenes in the aquifer migrated downgradient without being detected. These historical releases have probably increased ambient concentrations of COCs observed at the southern boundary of the Philips and former 901/902 Thompson Place sites.

Figure 6b shows the locations of the monitoring wells near the southern boundary of the Philips and former 901/902 Thompson Place sites, as well as the historical TCE and cDCE concentrations observed at those wells. These monitoring wells are located upgradient of the main COC sources at the respective sites, and thus the observed concentrations are likely representative of ambient groundwater conditions upgradient of the sites, especially after substantial remedial actions were begun in the 1990s. Table 5b also provides recent PCE,

TCE, and cDCE concentrations in shallow groundwater at the upgradient sources as well as at the southern boundary of the Philips and former 901/902 Thompson Place sites.

The observed levels of PCE, TCE, and cDCE in shallow groundwater at the southern boundary are within the anticipated range of the concentrations from the upgradient sources. Both the ICORE International and the Pilkington Barnes Hind sites have been closed by the Water Board (2009b, 2010a) while TCE concentrations were above the TCE cleanup goal for the former 901/902 Thompson Place site (Table 5b).

Although COCs were found primarily in the A-zone aquifer at the listed upgradient sources (Table 5a), it is possible that the COCs could have impacted the B-zone aquifer when historical water levels were much lower. Figure 6c shows the trend of groundwater fluctuation at the San Jose Index Well in the Santa Clara subbasin between 1915 and 2000 (SCVWD, 2001). Although groundwater elevations in the well are not indicative of actual groundwater elevations throughout the Santa Clara County, the trend demonstrates relative changes in groundwater level. It is noted that because of the general drought conditions during the late 1980s and early 1990s, most of the A-zone wells at the site were dry at the time the feasibility study was completed by HLA (1991). The occurrence of a lower water table could explain deeper COC impacts.

Recent advances in management of chlorinated solvent sites have shown that, even after source removal or containment, concentrations of chlorinated solvent compounds at a downgradient monitoring well may persist at a trace level above the cleanup goal for a long time (Sale et al., 2008). One of the primary factors contributing to such long concentration tailing is the presence of abrupt contact between comparatively stagnant low-permeability zones (e.g., silt or clay) and transmissive zones (e.g., sand), which is also a main feature of the regional aquifer system.

Most natural processes and remediation technologies preferentially target COCs in transmissive zones. When this occurs, constituents are released from the low-permeability zones back into the transmissive zones via diffusion and slow advection, resulting in observed long tailing effects (i.e. asymptotic conditions) in COC concentration versus time trends (Sale et al., 2008). **This process is also referred to as “rebound.”** Because the distances between the site and upgradient sources are at least 2,000 feet and because no remedial action was taken for these sources until recently, a significant amount of COC mass is likely to be stored in the low-permeability zones in between, sustaining trace levels of COCs in ambient groundwater. Therefore, the off-site upgradient groundwater conditions pose a significant challenge to achieving site cleanup to concentrations specified in the Order.



## 1.5 SUMMARY OF SITE RISKS

The Third Five-Year Review, issued by the Water Board and approved by U.S. EPA Region 9 in 2009, indicates that the remedy at the site is **“protective of human health and the environment**. The ISB groundwater program is making progress towards groundwater restoration. In the meanwhile, institutional controls are in place to prevent exposure. There is **no exposure risk from vapor intrusion”** (Water Board, 2009a). The following two subsections summarize how human health and ecological risks have been managed at the site.

### 1.5.1 Risks to Human Health

The BPHE performed in 1990 evaluated the following exposure routes for the site:

1. Exposure to COCs through contacting soil.
2. Exposure to COCs in soils through upward vapor migration.
3. Air exposure due to COC emission from air stripping.
4. Ingestion of COC-affected groundwater .
5. Inhalation of COC vapors from groundwater during showering or other domestic use activities.
6. Inhalation of VOC vapors that could have originated from groundwater.

Through implementing various remedies, these exposure routes have been addressed as described below.

Exposure routes (1) and (2) were eliminated in the early 1990s through a series of soil excavations, as concluded in the public health assessment report by the California Department of Health Services (now California Department of Public Health) in 1993. It is noted that the Water Board also issued a No Further Action letter to confirm that total VOC concentrations as reported in post-excavation confirmation soil samples were below the site cleanup standard of 1.0 milligrams per kilogram (mg/kg).

Exposure route (3), which was due to COC emission from air stripping, has been eliminated by passing through activated carbon the air that was emitted when air stripping was used to remove COCs in groundwater. It is noted that, currently, the ISB treatment at the site is operated under the monitoring-only mode, and no groundwater extraction occurs at the site. Exposure routes (4) and (5) have been eliminated through institutional controls in the form of a deed restriction, which limits the extraction of groundwater beneath the site, except for remediation or construction dewatering, thereby preventing direct domestic use of groundwater.

The understanding of exposure route (6) has changed significantly since 1990 when the BPHE was completed. At that time, vapor intrusion was not considered to pose unacceptable human risk for hypothetical future on-site residents (HLA, 1991). Now that vapor transport

mechanisms and toxicity of many VOCs have been further studied, vapor intrusion is generally considered to be a more important pathway . As described in the Second Five-Year Review in 2004, the U.S. EPA considered that the site might require evaluation of the potential of vapor intrusion (Water Board, 2004). In **response to EPA's concern**, AMD submitted a vapor intrusion assessment to the Water Board in 2007 (Geomatrix, 2007b). The assessment found that VOC concentrations in groundwater samples from certain monitoring wells located in the vicinity of the former 901 VOC source area exceeded the Water Board Environmental Screening Levels (ESLs). However, due to site-specific considerations, vapor intrusion was not a concern because:

- the new building at the site is a self-storage facility and was constructed on a 15-inch-thick concrete slab-on-grade foundation that would be an impediment to vapor intrusion,
- the office space of this new building is the only occupied portion of the building and is located 600 feet upgradient of the former source area, and
- the office building is ventilated by an HVAC system.

For these reasons, the assessment concluded that VOC concentrations in groundwater above ESLs should not cause an unacceptable risk to occupants of the on-site building. The Water Board and the U.S. EPA reviewed the assessment and concluded that there is no current exposure via the vapor intrusion pathway, as described in the Third Five-Year Review (Water Board, 2009a). However, the Water Board and the U.S. EPA recommended that additional samples be collected and evaluated if the use of the site building changes.

### 1.5.2 Ecological Risks

According to the Record of Decision (ROD) issued by the U.S. EPA in September 1991, the site did not constitute critical habitat for endangered species nor did it include or impact any wetlands; some endangered species, such as the California Clapper Rail and the Salt Marsh Harvest Mouse, were reported to exist in the tidal marshes of the San Francisco Bay (U.S. EPA, 1991). The statement above is still valid for the site.

It is believed that no exposure pathway exists for sensitive ecological receptors under current site conditions. Exposure to soils that may have been impacted by historical activities at the site is not expected because only a very limited area of the site ground is unpaved and because the portion of exposed ground has been covered with imported soils for landscaping. Exposure of ecological resources to contaminated groundwater is also not expected because the extent of regional COC-affected groundwater has been delineated and does not extend to any surface water body or wetlands. In summary, the site does not pose risks to ecological resources.

## 1.6 FATE AND MOBILITY OF COCs

Chemical fate is the tendency of a chemical to undergo transformation or degradation. Mobility is the tendency of a chemical to move along a pathway in response to a driving force. A chemical that is immobile and persistent in the environment tends to remain in place. The tendency toward immobility and persistence is a function of site-specific characteristics and of the potential and chemical properties of the chemicals. These properties include solubility; tendency to transform; tendency of organic compounds to degrade; chemical affinity for soils, organic matter, or air (usually described by a partition coefficient); and heterogeneity of hydraulic conductivity. The following subsections present the reactivity and physicochemical properties for site COCs.

### 1.6.1 Degradation and Transformation of Site COCs in Saturated Aquifer

The persistence and mobility of organic compounds are governed by their physicochemical properties and by transformation mechanisms that act on them. The results of groundwater quality monitoring obtained during the ISB treatment period indicate that complete reductive transformation can occur if suitable organic substrate is added. At the site, highly chlorinated VOCs (e.g., PCE and TCE) can undergo reductive dechlorination; however, less chlorinated VOCs (e.g., cDCE and VC) may require more time for their transformation.

### 1.6.2 Transport of Site COCs in Saturated Aquifer

The important physicochemical parameters for the COCs at the site include **Henry's law** constant for water and the organic carbon-to-water partition coefficient ( $K_{oc}$ ). Migration of contaminants can be discussed in a quantitative way by comparing their retardation factors, representing a ratio of the velocity of the contaminant to the velocity of groundwater. Contaminants that react with the solid phase (the aquifer) move at a slower rate than those that do not react with the solid phase. The retardation factor is computed from the following equation (Freeze and Cherry, 1979):

$$R = \frac{v_g}{v_c} = 1 + \left( \frac{\rho_b}{n} \times K_d \right) \quad (1)$$

where:

$R$  = retardation factor (unitless)

$v_g$  = groundwater velocity (ft/d)

$v_c$  = contaminant velocity (ft/d)

$\rho_b$  = bulk density (kg/L)

$n$  = porosity (unitless)

$K_d$  = distribution coefficient (L/kg)

As mentioned above, the distribution coefficient,  $K_d$ , of organic compounds can be expressed as  $K_{oc} \times f_{oc}$ . It should be noted that the values of  $\rho_b$ ,  $n$ , and  $f_{oc}$  vary with the type of geologic formations. The representative values of these parameters are provided in Table D-1 in Appendix D. The representative  $K_{oc}$  values for PCE, TCE, cDCE, and VC are listed on Figures C-1b, C-2b, C-3b, and C-4b, respectively, in Appendix C.

### 1.6.3 Influence of Aquifer Heterogeneity on Solute Transport in Saturated Aquifer

Most remedial technologies for chlorinated solvent release sites target impacted groundwater within transmissive zones. The overall premise of this approach is that COC-affected groundwater could be drawn out of aquifers or quickly destroyed in situ, to be replaced by clean, unaffected groundwater, thereby causing COC concentrations to drop below cleanup goals. Unfortunately, experience has shown that COCs present as gas in soil, and/or sorbed to solids, and/or dissolved in groundwater in low-permeability zones can act as long-term COC reservoirs that can sustain COC concentrations in groundwater for several decades in spite of aggressive remedial actions (Sale et al., 2008).

It has been shown that persistent COC sources facilitate the transport of dissolved COCs into the low-permeability zones via diffusion and/or slow advection, resulting in their long-term storage in dissolved and sorbed phases therein (this is called matrix storage). When the strength of the sources attenuates and as natural processes and/or remediation technologies preferentially deplete COCs in transmissive zones, COCs are often released from the low-permeability zones back into the transmissive zones via the same slow processes of diffusion and slow advection (Sale et al., 2008).

The following site conditions are believed to drive matrix storage effects and may result in persistent levels of COCs in groundwater that cannot be effectively remediated (Sale et al., 2008); these conditions are representative of many sites in the area, as discussed in Section 1.4.3.4, where:

- Transmissive zones are a small fraction of the aquifer's total volume.
- COCs are initially present at high concentrations.
- Substantial amounts of COC mass has been released.
- COCs in transmissive zones are transported adjacent to low-permeability zones over a long period of time (several years).

### 1.6.4 COC Volatilization from Groundwater

Henry's law constant is based on the equilibrium relationship between the solubility of a gas in water and the partial pressure of the gas in the atmosphere above the water. It reflects the tendency of a gas dissolved in liquid to transfer to the atmosphere and commonly used to measure the potential for vapor transport. The greater the value of Henry's law constant, the greater the tendency of the gas to be released into the air and transported into the

atmosphere. The lower the constant, the greater the tendency of the gas to remain dissolved in the liquid phase and the greater the potential to be transported by water. Because of the **absence or insignificance of the gaseous phase in the saturated zone**, Henry's law constant is more important for chemical transport evaluation in the unsaturated zone and for vapor intrusion evaluation. The **values of Henry's law constant at 25°C** for PCE, TCE, cDCE, and VC are provided on Figures C-1b, C-2b, C-3b, and C-4b, respectively, in Appendix C.

## 1.7 HISTORY OF REMEDIES IMPLEMENTED FOR SITE CLEANUP

The GWET system, groundwater monitoring, and institutional controls were the remedies selected for site groundwater cleanup; the basis for selecting these remedies is provided in the Order issued by the Water Board (1991) and the ROD issued by the U.S. EPA (1991), both in 1991. The GWET system used the air stripping process to remove COCs from the extracted groundwater prior to either permitted discharge to the storm sewer or on-site reuse. The GWET system at the site began in 1983 and continued operating through 2002, when it was discontinued to accommodate the ISB pilot testing.

Between December 2002 and September 2004, the pilot study was conducted to determine whether using ISB would expedite site cleanup. The primary findings and conclusions from the pilot study are as follows:

- Tracer test results indicated that a groundwater circulation system would be effective in distributing carbohydrate through the treatment zone.
- Carbohydrate was rapidly utilized by bacteria in the treatment zone and required a relative frequent or continuous carbohydrate injection stream to maintain the substrate level to promote the treatment of VOCs.
- TCE and cDCE were effectively reduced to their common, environmental benign products (e.g., ethene and chloride) when carbohydrate was present in sufficient quantities and duration. Results indicated that TCE, cDCE, and VC concentrations were reduced in pilot test wells by over 90 percent within six months.

The results of the ISB testing study led AMD to recommend expanding the ISB program as an alternative to the existing GWET system and as the final cleanup remedy for the site (Water Board, 2009a).

Following a subsurface investigation, AMD designed and installed a full-scale ISB system to expedite groundwater cleanup in the vicinity of the former 901 Thompson Place ANS. The ISB system extracted groundwater from downgradient extraction wells, treated it with granular activated carbon (GAC), and amended it with carbohydrate before injecting it into upgradient injection wells. The ISB system operated intermittently between December 2005 and May 2008 in order to accommodate certain ISB system modifications and site redevelopment, as well as to control carbohydrate consumption rates. The ISB is currently in monitoring mode (without groundwater recirculation and substrate addition) to observe the effects of passive,

ongoing bioremediation. During the period of the ISB program implementation, the air stripper and two, 2,000 pound GAC vessels remain as a backup on-site treatment system.

Basic system operation and performance data for these two remedies are compiled in Tables 6a and 6b. Table 6a provides the amount of groundwater extracted and VOC mass removed for the GWET and ISB systems. Table 6b summarizes representative groundwater extraction rates in 1995 and 2000/2001 and during the ISB implementation. Appendix B provides the results of capture zone simulations presented in the Second Five-Year Report (Arcadis, 2001).

## 1.8 COMPARATIVE PERFORMANCE EVALUATION FOR PUMP-AND-TREAT AND IN SITU BIOREMEDIATION

The cleanup time estimates presented in the Final Feasibility Study (HLA, 1991) indicated that, using a GWET system, it would take 18 years to achieve the TCE cleanup goal in the A zone, and 9 years in the combined B-zone aquifer. The method for estimating cleanup time was based on a simple batch flushing model, which did not take into account the mass exchange between transmissive and low-permeability zones and the strength of the COC sources in groundwater. According to the historical monitoring data, after the 10 years that had been estimated as the cleanup time, the TCE concentration observed at DW-1 (B1 zone) in 2001 was 1,400 µg/L (Appendix A), which was still over two orders of magnitude higher than the TCE cleanup goal, indicating that the GWET system was not as effective as it was thought to be in 1991.

It is generally agreed that using the pump-and-treat approach alone could not effectively remediate a heterogeneous aquifer for chemicals whose cleanup goals are low, since it is rather inefficient at removing COCs from low-permeability zones (U.S. EPA, 1996). In fact, the 901/902 Thompson Place site is specifically identified as one of the sites that would be most difficult to obtain cleanup goals using pump-and-treat in a 1994 text book on groundwater cleanup (National Research Council, 1994). The authors of this early textbook on groundwater cleanup recognized that when the mass removal rate of a GWET system decreases and approaches an asymptotic level, the controlling mass transfer mechanism is governed by diffusive processes, such as dissolution or desorption. One way to expedite the mass transfer process is to promote in situ chemical reactions, such as microbial reductive dehalogenation. As discussed in the comparison evaluation below, the ISB program implemented at the site has stimulated indigenous microbial activity and resulted in COC transformation in situ, greatly enhancing the mass transfer process and accelerating the COC mass removal:

### 1.8.1 Ex Situ Mass Removal Efficiency

Table 6a shows the comparison of the average VOC influent concentrations and mass removal efficiency of the GWET and ISB systems. Judging by the historical mass removal efficiency for the GWET system, the efficiency appears to reach a pseudo-steady state between 1996 and 2002, and the subsequent ISB implementation enhanced the removal

efficiency by three to five times in 2006 and 2007. The actual efficiency enhancement achieved by the ISB is probably substantially larger than three to five times, considering that the amount of COCs removed in situ is not included, which is expected to be a large portion of the total COC removal (Water Board, 2009a).

### **1.8.2 Change in Concentration Trends**

The historical concentration trends have been described in Section 1.4.3.3. As shown on Figures 5a through 5c, the observed COC concentrations sometimes fluctuate greatly. The fluctuation of TCE concentrations before the implementation of the ISB program might result from the following:

- removal of the COC sources in the vadose zone at the site,
- changes in hydrogeologic conditions due to variable recharge, and
- changes in groundwater extraction operation in the vicinity of the site.

Despite these fluctuations, a general trend is still discernable. Table 7a summarizes the historical TCE concentration trends as three time periods representing different phases of concentration reduction:

1. 1982–1992, the first GWET operation phase
2. 1992–2002, the second GWET operation phase
3. 2005–2008, the active ISB phase

A TCE concentration reduction by over one or two orders of magnitude was observed in most of the monitoring wells during the first period of groundwater extraction. However, the TCE concentration reduction in the second period was within one order of magnitude after additional pumping for 10 years. In contrast, the TCE concentration reduction during the approximately 30-month active ISB implementation period was over one order of magnitude. The comparison indicates that the ISB can accelerate the achievement of the TCE cleanup goal.

To evaluate whether the ISB reduces the mass flux of chlorinated ethenes, a comparison was made of total chlorinated ethene concentrations before and after active ISB implementation (Table 7b). The observed total concentrations of chlorinated ethenes in most wells were found to have decreased, and the fractions of biodegradation products (e.g., cDCE and VC) increased, indicating that the ISB is capable of reducing COC mass flux. There was no decrease in the total concentrations of chlorinated ethenes at 23-S and 23-D, located away from the main ISB treatment area (Figure 1d).

At DW-1, the total concentrations of chlorinated ethenes decreased approximately three orders of magnitude, and the concentrations of chlorinated ethenes observed in 2010

remained at the levels below or close to the cleanup goals even when the ISB system turned into a passive monitoring mode. Similarly, very low concentrations of chlorinated ethenes were maintained at DW-2. These results indicate that the ISB has great potential to accelerate site cleanup. The success can be related to the fact that DW-1 and DW-2 are both substrate injection wells. Injection pressure and high substrate concentration during the period of injection probably enhanced substrate penetration into the low-permeability zones nearby, thereby sustaining microbial reactions over a long period of time. This hypothesis is supported by sustained elevated TOC concentrations observed at these locations ( $>10$  mg/L) since the start of the full-scale ISB implementation in December 2005 (Figures 5a and 5b).

### 1.9 POTENTIAL ADVERSE EFFECTS OF HISTORICAL EXTRACTION ACTIVITY

Pump-and-treat has been widely used as a containment strategy since the 1980s. But this technology will not be appropriate to achieve restoration at many sites, due to unfavorable hydrogeologic conditions (discussed in Section 1.4). In the past, the design of a GWET system was primarily based on required pumping rates to achieve desired extent of cones of depression to capture impacted groundwater. Such a design approach does not critically analyze how impacted groundwater flows into the GWET system. When impacted groundwater is present across layered or extensively interbedded geologic settings, it is important to minimize the movement of groundwater across different hydrostratigraphic zones, thereby reducing the amount of COCs stored in the low-permeability zones.

AMEC has conducted an evaluation of the historical groundwater extraction activity at the site. It was found that, in 1995, the total pumping rate applied to the B2 zone was approximately two times larger than the total pumping rate applied to the A and B1 zones above (Table 6b). Such unbalanced pumping is likely to induce significant movement of impacted groundwater through the low-permeability zones between the A, B1, and B2 zones. The extraction rates applied in 2001/2002 appear to be more balanced. Nevertheless, since the locations of the pumping wells screened in the A1 and B1 zones (DW-1, DW-2, DW-3, DW-4, and DW-7) are far away from the pumping wells screened in the B2 zone (DW-6 and DW-8), the effects of unbalanced pumping are expected to still be present at that time.

In addition, the results of the hydraulic capture zone simulations performed by Arcadis (2001) indicate that the historical GWET activity likely captured a large amount of impacted groundwater from the adjacent Philips site (Appendix B). It is clear that the simulated capture zone for the B2 zone based on the representative pumping rates used in 1995 (Table 6b) extends at least 300 feet outside the western boundary of the site.

Therefore, while the historical operation of the GWET system had adequately contained impacted groundwater within the site boundary, it also created unintended consequences that may prolong the time required to achieve site cleanup with further pump and treat. This is



another important consideration when contemplating the long-term feasibility of pump-and-treat as a site cleanup technology.

## **2.0 REMEDIAL ACTION OBJECTIVES**

The overall purpose of remedial action is to protect human health and the environment. The specific objective for groundwater restoration is to reduce COC levels in impacted groundwater so that the groundwater can ultimately be used for domestic purposes. The following subsections present (1) a description of the remedy and cleanup standards selected the Water Board and U.S. EPA in 1991; (2) a discussion of the changes in Applicable or Relevant and Appropriate Requirements (ARARs) since the 1991 ROD was promulgated; (3) a discussion on potential site-specific remediation goals that may be considered along with ARARs, including risk-based concentrations and ambient groundwater concentrations; and (4) a summary of the proposed RAOs for the site.

### **2.1 REMEDY AND CLEANUP STANDARDS SELECTED BY REGULATORY AGENCIES**

Both the Order issued by the Water Board and the ROD issued by the U.S. EPA describe the following elements for the remedies selected for site groundwater cleanup:

- groundwater extraction;
- treatment of extracted groundwater by air stripping or ozone oxidation;
- discharge of treated water under National Pollutant Discharge Elimination System (NPDES) permit; and
- placement of a restrictive covenant prohibiting the use of shallow groundwater for drinking water.

The groundwater cleanup standards set therein were based on California proposed or adopted Maximum Contamination Levels (MCLs), which are more stringent than the U.S. EPA's MCLs in many cases. These cleanup standards (summarized in Table 8) remain in effect to date.

### **2.2 APPLICABLE OR RELEVANT AND APPROPRIATE REQUIREMENTS (ARARs)**

Remedial actions under CERCLA (as amended by the Superfund Amendments and Reauthorization Act) must comply with the substantive provisions of federal and state ARARs, as specified in CERCLA Section 121(d). Applicable requirements are those federal and state cleanup standards, standards of control and other environmental protection requirements, criteria, or limitations promulgated under federal or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site. If a requirement is not applicable, it may still be relevant and appropriate. A relevant and appropriate requirement addresses problems or situations that are substantially similar to those encountered at the CERCLA site.

A detailed ARARs analysis was performed during the Feasibility Study phase from the late 1980s to the early 1990s, and was documented in the Final Feasibility Study in 1991 (HLA,

1991). Since then, the Water Board and U.S. EPA have reviewed ARARs according to the site conditions during the Five-Year Review processes and have not found any change in ARARs that would affect operations of the remedy or protectiveness of the remedy in all three Five-Year Review Reports.

The only ARARs change indicated in the Five-Year Review processes is one of action-specific ARARs standards from the ROD, citing the NPDES discharge standards in accordance with the Regional Water Quality Control Plan for the San Francisco Bay region. The Basin Plan **references standards that were adopted from U.S. EPA's Ambient Water Quality Criteria, as** adopted by the Water Board in 1986. However, in 2000, the U.S. EPA promulgated the California Toxics Rule, which updates and adds standards for discharges to surface waters. Since the California Toxics Rule standards for VOCs are not lower than those in the NPDES permits for the groundwater treatment systems, these new standards do not affect the NPDES discharge standards for the treated effluent and they do not affect the protectiveness of the remedy.

### 2.3 TO-BE-CONSIDERED CRITERIA AND REMEDIATION GOALS

When ARARs are not available or are determined to be impracticable, site-specific remedial goals may be based on other information that does not qualify as an ARAR, identified as **"to be considered"** (TBC) criteria. TBC criteria may include federal, state, and local standards, limits, and guidance that have not been promulgated. Chemical-specific ARARs and TBC criteria are considered, in part, along with ambient concentrations and health risk-based concentrations (RBCs) in the development of site-specific remediation goals for the site remedy. The following two subsections discuss additional considerations that need to be taken into account for site cleanup.

The RBCs discussed and developed here are to be protective of people potentially exposed to COCs in site groundwater. RBCs are generally developed, using site-specific information when appropriate, for individual chemicals, specific media, and exposure scenarios. These RBCs may be considered along with applicable chemical-specific ARARs and ambient COC concentrations in groundwater when determining the site-specific remediation goals.

#### 2.3.1 Groundwater RBCs for Domestic Use

Several toxicity factors have been changed since the BPHE performed in 1990. In 2009, the U.S. EPA harmonized the risk-based screening levels for Regions 3, 6, and 9 into a single table, Regional Screening Levels (RSLs) for Chemical Contaminants at Superfund Sites (U.S. EPA, 2010). These RSLs are developed using risk assessment guidance from the U.S. EPA Superfund program. They are risk-based levels derived from standardized equations combining exposure assumptions with updated U.S. EPA toxicity data. The current RSL values are based on an incremental risk level of  $10^{-6}$  for carcinogens or a hazard quotient of 1

for noncarcinogens. A comparison of the cleanup standards specified in the ROD, the current RSLs, and the risk calculation (in excess of  $10^{-6}$ ) are presented in Table 9.

Based on the RSL values released in November 2010 for tap water, the RSLs for 1,1-DCA, 1,2-DCB, PCE, TCE, and vinyl chloride are lower than the current cleanup standards for the site. Among these five COCs, the most significant change in the ratio between the cleanup standard and the RSL is for PCE. The ROD chose the MCL of 5 µg/L to be the cleanup goal for PCE. Based on the new toxicity value, this would result in an incremental carcinogenic risk of  $4.55 \times 10^{-5}$ . Although the estimate of the risk increases, it is within U.S. EPA's acceptable risk range, between  $10^{-6}$  and  $10^{-4}$ , according to the National Contingency Plan (U.S. EPA, 1990). Therefore, the changes in the toxicity values do not increase the site risk to unacceptable levels. The cleanup levels specified in the ROD are considered to remain protective.

### 2.3.2 Groundwater RBCs for Vapor Intrusion Pathway

As stated in the Third Five-Year Review Report, the current site conditions are protective of human health with respect to exposure resulting from vapor intrusion. The Water Board and the U.S. EPA still recommend a more site-specific investigation of the potential of vapor intrusion at the site when a change in site building use occurs, because three COCs (PCE, TCE, and VC) in shallow groundwater exceed the generic screening levels established by the U.S. EPA. These generic levels are based on empirical data collected from numerous vapor intrusion investigations done nationally, regardless of subsurface soil types.

To better evaluate human health risks associated with the vapor intrusion pathway, a set of semi-site-specific groundwater RBCs for vapor intrusion has been developed based on the Tier 2 evaluation approach described in the *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils* (U.S. EPA, 2002). Although the process of developing RBCs has inherent uncertainties associated with the calculations and assumptions, conservative assumptions and approaches were used that would tend to estimate the RBC as lower than it actually needs to be for protection of human health. In general, where uncertainties existed in input parameters, reasonable conservative values (i.e., values that led to higher estimates of exposure) were chosen.

The approach that was used to develop RBCs follows the guidance published by the U.S. EPA and the San Francisco Regional Water Board and is documented in Appendix C of this report. These results are summarized in Table 10. The proposed RBCs for the vapor intrusion pathway fall between the generic screening levels developed by the U.S. EPA (2010) and the ESLs for vapor intrusion developed by the Water Board (2008b). The RBCs represent the concentrations of COCs that could remain in groundwater without posing unacceptable human health risks to current and future on-site populations through the vapor intrusion pathway.

### 2.3.3 Upgradient Groundwater Concentrations

Another consideration in establishing site-specific cleanup goals for environmental media at the former AMD 901/902 Thompson Place site is COCs from upgradient sources. As discussed in Section 1.4.7, these COCs are widespread in groundwater at concentrations that substantially exceed ARARs and MCLs. For instance, the ICORE international and Pilkington Barnes Hind sites were closed by the Water Board when PCE and TCE concentrations in groundwater remained above their respective California MCLs (Table 5b). The criteria for bringing these sites to closure were as follows:

- The site investigations and remedial actions for soil and groundwater contamination at the site were complete to the extent practicable.
- The PCE and TCE concentrations in groundwater are decreasing and attenuating naturally, as evidenced by increasing concentration of breakdown products such as cDCE.
- The **COC concentrations are below the Water Board's groundwater screening levels** for potential vapor intrusion concerns for residential land use.
- The remaining VOC-impacted groundwater beneath the site is probably from off-site upgradient sites.
- The **site meets the Water Board's low-threat case closure criteria** (Water Board, 2009b, 2010a).

For the former AMD 901/902 Thompson Place site, it may be impracticable to achieve a cleanup goal at the site that is lower than upgradient groundwater concentrations. Under such circumstances, it is appropriate to establish a set of provisional site-specific cleanup goals that are consistent with the local regulatory framework and groundwater quality upgradient.

## 2.4 SUMMARY OF REMEDIAL ACTION OBJECTIVES AND PROPOSED SITE-SPECIFIC REMEDIATION GOALS

Section 2.0 has presented the remedy and cleanup standards selected by the Water Board and U.S EPA and reviewed the changes to ARARs after the issuance of the ROD. The TBC criteria regarding RBCs for groundwater for domestic use and for vapor intrusion concerns were evaluated. Based on the evaluation, the cleanup goals specified in the ROD are still considered adequate and a set of semi-site-specific screening levels were developed that can provide acceptable protection to human health from vapor intrusion exposure. The most difficult technical challenge for site cleanup is that the concentrations of certain site-related COCs in upgradient groundwater are significantly higher than the cleanup goals specified in the ROD. It is recommended that a set of provisional site-specific cleanup goals be established through more detailed monitoring of representative COC concentrations in groundwater passing through the southern boundary of the former 901/902 Thompson Place site and adjacent Philips site. The provisional cleanup goals can serve as a decision point for

shifting from more aggressive remedial actions (e.g., ISB) to more passive remedies (e.g., monitored natural attenuation) at the site.

### 3.0 IDENTIFICATION AND SCREENING OF TECHNOLOGIES

This section summarizes and documents the development and screening of remedial technologies for the FFS. As described in the 1991 ROD (U.S. EPA, 1991), a spectrum of general response actions (GRAs) and associated remedial technologies were evaluated in order to select a remedy for the site. Since the completion of the *Final Feasibility Study for the Companies* in 1991 (HLA, 1991), many new technologies have emerged and some widely used technologies have matured or have been improved. In general, the understanding of the limitations and advantages of various technologies has advanced greatly. Therefore, it is imperative that the effectiveness of various technologies and process options be re-evaluated before preparing a revised cleanup plan for expediting site cleanup.

According to U.S. EPA Remedial Investigation/Feasibility Study (RI/FS) guidance (U.S. EPA, 1988), the technology screening consists of three phases, as follows: (1) identifying GRAs that are applicable to the site; (2) performing initial screening for technologies and process options associated with each GRA based on technical implementability; and (3) performing secondary screening for process options retained after the initial screening, on the basis of effectiveness, implementability, and cost. The process options retained after the secondary screening are then used to form various remedial alternatives for further evaluation. Details regarding the development of the GRAs and screening of technologies are provided below.

#### 3.1 GENERAL RESPONSE ACTIONS

GRAs are media-specific actions that satisfy RAOs that have been developed for the site. The GRAs considered in the FFS for groundwater at the site are summarized below.

- **No Further Action.** Evaluation of a “no action” alternative or a “no further action” alternative is required under the National Contingency Plan (NCP; U.S. EPA, 1990). For this GRA, it is assumed that no further action means that no further remedial or monitoring activities would occur.
- **Monitoring Only.** Impacted groundwater may be monitored on a periodic basis to ensure that chemical concentrations do not increase such that there is an unacceptable risk to human health or the environment.
- **Institutional Controls.** Institutional controls are legal or physical means to prevent potential exposures to COCs by limiting the use of contaminated property (e.g., use of site groundwater for domestic purposes).
- **Monitored Natural Attenuation.** Monitored natural attenuation relies on natural processes to achieve site-specific remedial objectives. The natural attenuation processes include physical, chemical, or biological processes that, under favorable conditions, act without human intervention to reduce the mass, toxicity, mobility, volume, or concentrations of contaminants in groundwater. Groundwater would be monitored on a periodic basis to ensure that chemical concentrations do not

increase such that there is an unacceptable risk to human health or the environment

- **Passive Containment.** This response action reduces the mobility of COCs, eliminates exposure pathways, and prevents the migration and transport of COCs to unaffected media using impermeable barriers.
- **Active Containment.** This response action reduces the mobility of COCs, eliminates exposure pathways, and prevents the migration and transport of COCs to unaffected media using hydraulic control.
- **Ex Situ Groundwater Treatment.** This response action provides for the treatment of extracted groundwater from dewatering operations prior to disposal.
- **In Situ Treatment.** This response action reduces the mobility of COCs, eliminates exposure pathways, and prevents the migration and transport of COCs to unaffected media.
- **Disposal of Site Liquids from Treatment.** This response action provides for the disposal of treated site liquids resulting from groundwater extraction operations.

### 3.2 INITIAL SCREENING OF REMEDIAL TECHNOLOGIES AND PROCESS OPTIONS

After the GRAs are identified, potentially applicable technology types and process options can be identified, evaluated, and screened for each response action. Technology types and process options are then screened to retain implementable technologies that could be used in the development of remedial alternatives. During this initial screening step, process options are eliminated from further consideration on the basis of technical implementability (either as a stand-alone remedy or as a component of an overall remedial option). Readily available data concerning site characteristics and chemical distributions are used to screen out technologies and process options that cannot be effectively implemented at the site. In most cases, a process option belongs to a specific GRA. The process options belonging to this category retained after the initial screening are presented in Table 11a. There are a few process options that can be used to enhance various technologies. For example, the fracturing technology can enhance groundwater extraction to achieve better hydraulic containment and provide better chemical delivery for various in situ technologies. The screening results of such process options are presented in Table 11b.

### 3.3 SECONDARY SCREENING OF PROCESS OPTIONS

During this stage of the screening process, and consistent with U.S. EPA RI/FS guidance (U.S. EPA, 1988), process options that are retained from the initial screening process are further evaluated and screened on the basis of effectiveness, implementability, and cost. Process options are eliminated from further consideration if other process options within the same technology type offer significant relative advantages. The purpose of this screening step is to minimize the number of process options that must be considered, without limiting the flexibility of the remedial design. The criteria for secondary screening are discussed in the following subsections.

### **3.3.1 Effectiveness**

The effectiveness of process options that are considered to be technically implementable is evaluated in comparison with other process options within the same technology type. This evaluation focuses on (1) the potential effectiveness of process options in handling the estimated areas or volumes of media and meeting the remediation goals identified in the RAOs; (2) the potential impacts to human health and the environment during the construction and implementation phase; and (3) the proven performance and reliability of the process with respect to the contaminants and conditions at the site.

### **3.3.2 Implementability**

Implementability encompasses both the technical and administrative feasibility of implementing a process option. Since technical implementability is used as a screening criterion during initial screening to eliminate technology types and process options, this secondary screening process places more emphasis on the institutional aspects of implementability. This includes the ability to obtain necessary permits, the availability of treatment, storage, and disposal facilities, and the availability of equipment and skilled workers necessary to implement the process option.

### **3.3.3 Cost**

At this stage in the FS process, relative capital and operations and maintenance (O&M) costs are qualitatively compared using engineering judgment. Each process is evaluated as to whether costs are high, medium, or low compared with other process options in the same technology type.

The secondary screening resulted in the retention of 17 process options that could be applicable as components of remedial alternatives at the site. Process options retained for the site are presented in Tables 12a and 12b.

## **3.4 RESULTS OF SECONDARY SCREENING PROCESS OPTIONS**

Of the 30 process options that were retained for further evaluation after the initial screening step, 17 were selected for remedial alternative development. Detailed descriptions of these process options are provided below.

### **3.4.1 Groundwater Sampling and Monitoring**

Groundwater sampling and monitoring involve sampling existing monitoring wells; this has been conducted to delineate the extent of impacted groundwater at the site. Periodic groundwater sampling will be conducted to monitor the progress of the site remedy and to verify its effectiveness in meeting RAOs. Additional groundwater monitoring work may be conducted to establish the ambient groundwater conditions from the off-site upgradient sources, as discussed in Section 2.3.3.

### **3.4.2 Institutional Controls – Groundwater Access Restriction**

The U.S. EPA typically describes institutional controls as non-engineered measures, such as administrative and/or legal controls, that minimize the potential for human exposure to impacted groundwater by limiting land or resource use. The existing restrictive covenant does not allow for the following land use at the site: food raising, hospital use, children's day care and elderly care use, residence use, and public or private schools for persons under 21 years old. No groundwater extraction without approval is allowed except for site remediation, and activities disturbing the remedy and monitoring systems without approval are prohibited.

### **3.4.3 Monitored Natural Attenuation**

Natural attenuation is the process by which VOC concentrations in groundwater are reduced by processes such as volatilization, dispersion, adsorption, and biodegradation. Site groundwater data indicate that anoxic or anaerobic conditions generally appear to be present in groundwater in the primary areas of concern at the site. These conditions are conducive to biological degradation of PCE and TCE. Other natural attenuation mechanisms such as advection, dispersion, adsorption, and volatilization may result in declining concentrations of VOCs over time such that groundwater meets RAOs. Monitored natural attenuation could be used in conjunction with other technologies in certain areas of the site to meet RAOs

### **3.4.4 Groundwater Extraction**

Hydraulic containment is one of the most widely used methods to limit the movement of impacted groundwater from source zones and to control the transport of site-related COCs. Through the use of extraction wells, impacted groundwater can be captured and treated ex situ—the pump-and-treat approach. Given its widespread use, the effectiveness of hydraulic containment for meeting various objectives for different types of sites is widely documented. Groundwater extraction can often be used to effectively prevent further transport of impacted groundwater, thus providing a reliable method of meeting RAOs at a specific point-of-compliance. However, the effectiveness of groundwater extraction is significantly limited in a highly heterogeneous aquifer or aquifer zones with low hydraulic conductivity. The technology is relatively easy to operate and has relatively low capital costs in comparison with other active remedial technologies. Disadvantages include the potential for relatively high operational and maintenance costs (primarily associated with treatment of extracted groundwater) and the potential for long-term operation, particularly in boundary containment applications.

For source zone remediation, injection wells can potentially be used in conjunction with extraction wells to hydraulically isolate contaminant source zones, thereby enhancing COC removal through water flushing. Groundwater extraction alone will typically not be an effective method for source remediation due to mass transfer limitation and the necessity of long-term operation. It can, however, potentially be used as a short-term strategy to prevent impacted



groundwater from flowing away from source areas, or it can be used as a component in source area remediation in conjunction with other technologies.

#### **3.4.5 Groundwater Treatment – Air Stripping**

Air stripping is an ex situ technology in which VOCs are partitioned from extracted groundwater by greatly increasing the surface area of the contaminated water exposed to air. Types of aeration methods include packed towers, diffused aeration, tray aeration, and spray aeration. Air stripping involves the mass transfer of volatile contaminants from water to air. For groundwater remediation, this process is typically conducted in a packed tower or an aeration tank.

#### **3.4.6 Groundwater/Vapor Treatment – Carbon Adsorption**

Carbon adsorption is a widely used ex situ technology in which water or vapor containing organic compounds is passed through one or more vessels containing activated carbon to which chemicals adsorb. Granular activated carbon (GAC) systems typically consist of one or more vessels filled with carbon connected in series and/or parallel, operating under atmospheric pressure. Adsorption by activated carbon has a long history of use in treating municipal, industrial, and hazardous wastes. The reactor configuration for the on-site aqueous-phase carbon adsorption system is the fixed bed, whereby a bed of activated carbon media is present within a vessel through which the aqueous stream is passed. When the GAC media is saturated with VOCs, the activated carbon media requires replacement.

#### **3.4.7 Groundwater Treatment – Ex Situ Biological Processes (Aerobic/Anoxic and Anaerobic Bioreactors)**

Although the use of ex situ biological processes for the treatment of extracted groundwater containing organics has become common in recent years, only a few reported field demonstration projects use this method to treat chlorinated ethenes in groundwater. This is because it is difficult to economically treat trace levels of chlorinated ethenes ex situ using biological processes alone. However, biological processes can enhance the effectiveness of an aqueous-phase carbon adsorption system. Based on the historical influent and effluent chemical monitoring data of the aqueous-phase GAC system (AMEC, 2011), anaerobic microbial reductive dehalogenation might have occurred in the carbon vessels when influent carbohydrate concentrations were high, which reduced the time required for replacement of carbon. Because VC is weakly sorbed by carbon and because it has a lower effluent standard, VC probably controls the timing for carbon replacement. To extend the life of carbon, the GAC system at the site may potentially be expanded to a system of aerobic/anoxic sequencing bioreactors to facilitate cDCE and VC aerobic biodegradation. A cost-benefit analysis is needed to evaluate the comparative merits of an integrated ex situ GAC treatment system augmented with biological treatment processes.

#### **3.4.8 In Situ Chemical Reduction**

This technology can be used for both boundary mass flux control and source zone remediation. The treatment mechanism involves the addition of a reducing agent such as zero-valent iron (ZVI), which degrades chlorinated organic compounds such as chlorinated ethenes via reductive dehalogenation. As the iron is oxidized, a chlorine atom is removed from the compound by one or more reductive dechlorination mechanisms, using electrons supplied by the oxidation of iron. To mitigate impacted groundwater within the site boundary, chemical reducing agents such as ZVI can be emplaced in the saturated zone to form a permeable reactive barrier (PRB) through which the impacted groundwater will flow. Because of space constraints in the vicinity at the northern site boundary, it is probably difficult to install a conventional PRB. Instead, a network of closely-spaced large diameter borings backfilled with ZVI could be installed at the site boundary. AMEC has implemented such a system at a former aerospace facility in Palo Alto, California.

#### **3.4.9 In Situ Enhanced Anaerobic Microbial Degradation**

Enhanced anaerobic bioremediation involves the stimulation of suitable microorganisms within a subsurface aquifer by delivering chemical amendments to the impacted zones. Subsurface microorganisms are stimulated by subsurface injection of electron donors (carbon source) and nutrients. In this process, site-related COCs are treated in situ, reducing the extent and mass of impacted groundwater, as demonstrated by the full-scale ISB program implemented at the site. To effectively control the release of COCs from the low-permeability zones in the site aquifer system, it is likely that a few additional soluble substrate injections or a one-time, long-term, slow-releasing substrate injection is needed. Hydraulic manipulation (groundwater circulation) and/or point injection may be used to enhance the penetration of substrate into the low-permeability zones.

#### **3.4.10 Pneumatic Fracturing**

This technology has been used to increase formation permeability to enhance extraction yield, as well as substrate, chemical, and particle delivery, in the subsurface. Pneumatic fracturing cannot be implemented using existing wells. New pneumatic fracture wells have to be drilled in the vadose and saturated zone and left open (uncased) for most of their depth. A packer system is used to isolate small (0.5 to 3.3 foot) intervals so that short bursts (~20 seconds) of compressed air (less than 200 pounds per square inch) can be injected into the interval to fracture the formation. The process is repeated for each interval within the impacted zones. Typically, up to 15 to 25 fractures per day with a fracture radius of 15 to 20 feet may be achieved to depths of 50 to 100 feet bgs. In certain situations, refracturing may be required at 6- to 12-month intervals. This fracturing method may promote more uniform delivery of treatment fluids and accelerated extraction of mobilized COCs. This technology has been used

in conjunction with soil vapor extraction (SVE), in situ bioremediation, in situ chemical reduction using ZVI, and pump-and-treat remediation.

#### **3.4.11 Directional Well**

Drilling techniques are used to position wells horizontally, or at an angle, to reach target zones not accessible by direct vertical drilling. Directional drilling may be used to enhance either in situ or in-well technologies such as groundwater pumping, bioventing, SVE, soil flushing, and in-well air stripping.

#### **3.4.12 Discharge – Surface Water**

The discharge of treated groundwater under an NPDES permit is a feasible option for the site. The site held a NPDES permit to discharge treated water to the nearby storm drain. The site was permitted for the discharge of treated wastewater at a flow rate of up to 70 gallons per minute (gpm).

#### **3.4.13 Discharge – Water Reclamation**

Water reuse was part of the remedy specified in the 1991 ROD (U.S. EPA, 1991). Treated water would be required to meet RAOs as well as water quality standards for specific applications such as irrigation of landscape and agriculture, dust control, soil compaction, decorative pond, fountain supply, industrial water supply, or drinking water supply. In the past, the treated water was reclaimed for use in the cooling tower operation at the site.

#### **3.4.14 Discharge – Injection Wells**

A portion of or all the treated water may be injected into the aquifer on site. The ISB implementation at the site has used injection wells for substrate delivery.

### **4.0 DEVELOPMENT OF REMEDIAL ALTERNATIVES**

The remedial technologies and process options retained following the secondary screening presented in Section 3.0 have been assembled into various remedial alternatives. These remedial alternatives incorporate remedial technologies that are designed to meet RAOs. The remedial alternatives that have been identified for evaluation in the FFS are presented below.

- Remedial Alternative 1: No Further Action.
- Remedial Alternative 2: Groundwater extraction and treatment.
- Remedial Alternative 3: Monitored natural attenuation in the A-zone and groundwater extraction and treatment in the B-zone.
- Remedial Alternative 4: In situ bioremediation and monitored natural attenuation.
- Remedial Alternative 5: Permeable reactive barrier.

Table 13 summarizes the major components of these remedial alternatives, which are described in more detail below.

#### **4.1 ALTERNATIVE 1: NO FURTHER ACTION**

Evaluation of a “no action” alternative or a “no further action” alternative, is required under the NCP. No Further Action forms the baseline for comparative evaluation presented in the following sections. This remedial alternative assumes that no further remedial or monitoring actions occur at the site.

#### **4.2 ALTERNATIVE 2: GROUNDWATER EXTRACTION AND TREATMENT**

This remedial alternative is the same as the remedy specified in the Order (Water Board, 1991) and the 1991 ROD (U.S. EPA, 1991), which consists of a GWET system, groundwater monitoring, institutional controls, and discharge of treated water to storm drains or reuse of treated water. The groundwater extraction rates are assumed to be the same as the rates used in 2001/2002 (Table 6b).

The alternative can achieve adequate containment of impact groundwater. The remediation time frame is expected to be controlled by site-related COC mass stored in the low-permeability zones and, potentially, some uncharacterized offsite sources. One disadvantage of this alternative is that it is prone to enhance the movement of impacted groundwater across the low-permeability zones, as discussed in Section 1.9.

#### **4.3 ALTERNATIVE 3: MONITORING NATURAL ATTENUATION IN THE A ZONE AND GROUNDWATER EXTRACTION AND TREATMENT IN THE B ZONES**

This remedial alternative consists of (1) continuation of the current annual groundwater monitoring program, (2) continuation of the ISB monitoring program for the A-zone wells, (3) use of groundwater extraction and treatment to remediate the B1 and B2 zones, and (4) discharge of treated water to storm drains or reuse of treated water.

For this alternative, the groundwater extraction rates are assumed to be half of those used in 2001/2002 (Table 6b). The rationale for using smaller extraction rates is that, based on the second Five-Year Report by Arcadis (2001), the rates used in 2001/2002 created excessively large capture zones for the B1 and B2 zones. Judging by the sizes of the simulated capture zones (Appendix B), halved extraction rates would probably be sufficient to contain impacted groundwater resulting from known COC sources on site. The remediation time frame is expected to be slightly longer than for Alternative 2 because smaller pumping rates reduce the extent of aquifer flushing.

It is noted that active extraction from the B1 and B2 zones in 1995 and 2001/2002 significantly reduced the water yield from the A zone (Table 6b, see extraction rates for wells exclusively screened in the A zone), partly because of the leaky nature of the low-permeability zones between the A and B1 zones (HLA, 1991). The rationales for using the Monitoring Natural Attenuation (MNA) approach for the A zone are that COC concentrations in shallow

groundwater have greatly reduced as a result of the ISB since 2005 and that future active pumping at the B zones is likely to further limit the mass flux in the A zone.

#### **4.4 ALTERNATIVE 4: IN SITU BIOREMEDIATION AND MONITORING NATURAL ATTENUATION**

This remedial alternative consists of (1) continuation of the current annual groundwater monitoring program, (2) continuation of the ISB monitoring program, (3) use of ISB either through substrate recirculation or direct injection, and (4) reinjection of treated water.

The results of the ISB implementation at the site so far suggest that the ISB approach shows great potential of accelerating site cleanup. It has been demonstrated that the biogeochemical conditions at the site favor COC degradation when sufficient substrate is provided. Currently, the COC concentrations at the source area near the former 901 Thompson Place building have been effectively reduced at many locations to the levels below or close to the cleanup standards, and significant COC concentration reduction has also been observed at many monitoring wells.

MNA can play an important role when the ISB system has reduced the site-related COC levels close to representative upgradient ambient concentrations in groundwater. At that time, the ISB system can be operated at the monitoring-only mode to assess whether MNA can effectively eliminate concentration rebound that results from back diffusion from the low-permeability zones. The remediation time frame for this alternative is expected to be shorter than the times for other alternatives because promoting COC degradation in situ can enhance COC desorption from the low-permeability zones and reduce COC concentrations in them.

#### **4.5 ALTERNATIVE 5: PERMEABLE REACTIVE BARRIER**

This remedial alternative consists of (1) continuation of the current annual groundwater monitoring program, (2) installation of a PRB, and (3) a performance monitoring program for the PRB. The time required for remediation using this alternative is expected to be longer than for Alternatives 2 and 3 because there is no active remediation targeting the source area upgradient of the PRB. In other words, the PRB is strictly a containment approach, and unless used in conjunction with other technologies such as ISB, the PRB itself will not expedite site cleanup, although COC concentrations downgradient of the PRB are expected to decrease more rapidly over time.

When installed properly, PRB can effectively reduce or eliminate site-related COC mass flux at the site boundary. However, limited access to the site for large, heavy equipment is likely to prevent installation of a conventional continuous PRB trench. An alternative way to construct a PRB is to use a dense network of soil columns containing ZVI. The ZVI soil columns can be constructed with bentonite layers placed across the low-permeability zones to prevent vertical flow of groundwater and VOCs from one depth to another within the reactive columns.

## **5.0 DETAILED EVALUATION OF REMEDIAL ALTERNATIVES**

The detailed analysis of remedial alternatives presents the relevant information needed to compare the remedial alternatives assembled for the FFS. The analysis of alternatives comes after the development of alternatives and before the selection of a final remedy. The detailed analysis of alternatives consists of the following parts: (1) a detailed evaluation of each alternative using seven of the nine NCP evaluation criteria (the final two criteria of Community Acceptance and State Acceptance are completed after public comment) and (2) a comparative evaluation. In this section, the first part of the analysis is presented. The second part, comparative evaluation of the alternatives, is presented in Section 6.0.

Screening of alternatives was not needed because the number of alternatives was not excessive for detailed evaluation. The extent to which alternatives are fully evaluated during the detailed analysis is influenced by the available data and the number and types of alternatives being analyzed. Section 5.1 presents the evaluation criteria, and Section 5.2 presents the evaluation of individual alternatives using the seven NCP criteria.

### **5.1 EVALUATION CRITERIA**

In accordance with the NCP, remedial actions have the following requirements:

- Be protective of human health and the environment.
- Attain ARARs or provide grounds for invoking a waiver of ARARs that cannot be achieved.
- Be cost-effective.
- Utilize permanent solutions and alternative treatment technologies or resource-recovery technologies to the maximum extent practicable.
- Satisfy the preference for treatment that reduces toxicity, mobility, or volume (TMV) as a principal element.

In addition, the NCP emphasizes the long-term effectiveness of remedial actions and related considerations, such as the following:

- The long-term uncertainties associated with land disposal.
- The goals, objectives, and requirements of the Solid Waste Disposal Act.
- The persistence, toxicity, and mobility of hazardous substances and their constituents, and their propensity to bio-accumulate.
- The short- and long-term potential for adverse health effects from human exposure.
- Long-term maintenance costs.
- The potential for future remedial action costs if the selected remedial action fails.
- The potential threat to human health and the environment associated with excavation, transportation, disposal, or containment.

Provisions of the NCP require that each alternative be evaluated against nine criteria listed in 40 CFR 300.430(e)(9). These criteria were published in the March 8, 1990, Federal Register to provide grounds for comparing the relative performance of the alternatives and to identify their advantages and disadvantages. This approach is intended to provide sufficient information to adequately compare the alternatives and select the most appropriate alternative for implementation at the site as a remedial action. The criteria are divided into three groups: *threshold*, *balancing*, and *modifying criteria*. Threshold criteria must be met by a particular alternative for it to be eligible for selection as a remedial action. There is little flexibility in meeting the threshold criteria: if they are not met by a particular alternative, then that alternative is not considered acceptable. The two threshold criteria are overall protection of human health and the environment, and compliance with ARARs.

If ARARs cannot be met, a waiver may be obtained in situations where one of the six exceptions occurs that is listed in the NCP; see 40 CFR 300.430(f)(1)(ii)(C)(1 to 6).

Unlike the threshold criteria, the five balancing criteria weigh the trade-offs between alternatives. A low rating on one balancing criterion can be compensated by a high rating on another. The five balancing criteria are as follows:

1. Long-term effectiveness and permanence
2. Reduction of toxicity, mobility, or volume through treatment
3. Short-term effectiveness
4. Implementability
5. Cost

The two modifying criteria are evaluated according to comments received from the public and relevant regulatory agencies. They are used to change the selection of the recommended alternative. The modifying criteria are community acceptance and state acceptance.

The following describes the threshold and balancing criteria in more detail.

#### **5.1.1 Threshold Criteria – Overall Protection of Human Health and the Environment**

Protection is the primary requirement that remedial actions must meet under CERCLA. A remedy is protective if it adequately eliminates, reduces, or controls all current and potential risks posed by the site through pathways. The assessment against this criterion describes how the alternative achieves and maintains protection of human health and the environment. Typically, assessment of overall protectiveness from COCs is based largely on the degree of certainty that an alternative can meet the established RAOs that are intended to prevent the exposure to site-related chemicals at concentrations of potential health or environmental concern.

### 5.1.2 Threshold Criteria – Compliance with ARARs

Compliance with ARARs is one of the statutory requirements of remedy selection. ARARs are cleanup standards, standards of control, and other substantive environmental statutes or regulations that are either “applicable” or “relevant and appropriate” to the CERCLA cleanup action (42 USC 9621 [d] [2]). Applicable requirements address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site. Relevant and appropriate requirements are those that, while not applicable, address problems or situations that are similar enough to those encountered at the CERCLA site that their use is well suited to environmental or technical factors at a particular site. The assessment against this criterion describes how the alternative complies with ARARs or presents the rationale for waiving an ARAR. ARARs can be grouped into three categories:

- **Chemical-specific.** ARARs are health- or risk-based numerical values or methodologies that, when applied to site-specific conditions, establish the amount or concentration of a chemical that may remain in or be discharged to the environment.
- **Location-specific.** ARARs restrict the concentration of hazardous substances or the conduct of activities solely because they are in specific locations, such as flood plains, wetlands, historic places, and sensitive ecosystems or habitats.
- **Action-specific.** ARARs include technology- or activity-based requirements that set controls, limits, or restrictions on design performance of remedial actions or management of hazardous constituents.

### 5.1.3 Balancing Criteria – Long-Term Effectiveness and Permanence

This criterion reflects CERCLA's emphasis on implementing remedies that will ensure protection of human health and the environment in the long term as well as the short term. This criterion also addresses how well a remedy maintains protection of human health and the environment after RAOs have been met to the extent feasible. Components to be addressed include the magnitude of residual risk at a site after completing a remedial action or enacting a no action alternative, as well as the adequacy and long-term reliability of institutional controls and containment systems.

### 5.1.4 Balancing Criteria – Reduction of Toxicity, Mobility, and Volume through Treatment

This criterion addresses the statutory preference for remedies that use treatment as a principal element. The assessment against this criterion evaluates the anticipated performance of the specific treatment technologies adopted by an alternative. The criterion is specific to evaluating only how treatment reduces toxicity, mobility, or volume.



### **5.1.5 Balancing Criteria – Short-Term Effectiveness**

This criterion concerns protection of human health and the environment during construction and implementation. Issues to be considered are the time required to achieve protection, short-term reliability of remedial technologies, protection of workers and the community during construction, and potential disruptions to residential neighborhoods.

### **5.1.6 Balancing Criteria – Implementability**

Implementability is assessed by considering the technical and administrative feasibility of each alternative as well as the availability of needed goods and services. Other considerations include the ability to construct and operate remedial facilities, ease of undertaking additional remedial actions, ability to monitor remedial effectiveness, and ability to obtain needed approvals and permits.

### **5.1.7 Balancing Criteria – Cost**

Cost encompasses all engineering, design, construction, and O&M costs incurred over the life of a project. The assessment against this criterion is based on the estimated present worth of these costs for each alternative. Present worth is a method of evaluating expenditures such as construction and O&M that occur over different lengths of time. This allows costs for remedial alternatives to be compared by ascribing all costs to the year that the alternative is implemented. The present worth of a project represents the amount of money that, if invested in the initial year of the remedy and disbursed as needed, would be sufficient to cover all costs associated with the remedial action. Note that five-year review costs, which are considered periodic costs, are not included in the alternative costs. As stated in the RI/FS guidance (U.S. EPA, 1988), these estimated costs are expected to provide an accuracy of +30 to –50 percent.

Informative sources for estimating costs can include results from treatability study results, quotations from vendors, discussions with construction contractors, standard engineering indices, and experience with similar projects. The level of detail required to analyze each alternative against these evaluation criteria depends on the nature and complexity of the site, the types of technologies and alternatives being considered, and other project-specific considerations. The analysis is conducted strictly for comparing the alternatives, understanding the significant aspects of each alternative, and identifying the uncertainties associated with the evaluation.

To cost monetary values of operations and maintenance of related process options, it is necessary to estimate remediation time-frames for individual alternatives. The time-frame is a quantity that strongly depends on transport behavior of site-related COCs in a aquifer system, and thus chemical transport modeling is often required to facilitate a quantitative or qualitative analysis of remediation time-frame. Because of complex site hydrogeologic conditions, it is not possible to confidently quantify the remediation time-frames for individual alternatives. A semi-

quantitative analysis was conducted to facilitate comparative evaluation of remediation time-frame and is presented in Appendix D. For the purpose of cost estimation for this Focused Feasibility Study, the remediation time frame for technologies relying upon slow COC back-diffusion from the low-permeability zones, such as groundwater extraction and treatment, MNA, and/or a aPRB, is set to be 30 years. The remediation time frame for the ISB process is set to be 7 years.

Table 14 provides a cost estimate for each of the alternatives. Appendix E provides more detailed information regarding the assumptions and rationales used for cost estimation. The estimated costs for Alternatives 1 through 4 are projected based on actual costs incurred for the GWET operations and ISB implementation at the site in the past, and thus are expected to be reliable. The cost for Alternative 5 is estimated based on AMEC's **past experience** from a PRB installation and monitoring project at a facility located 8 miles west-northwesterly from the site.

The final costs of the project and the resulting feasibility will depend on actual labor and material costs, competitive market conditions, actual site conditions, the final project scope, the implementation schedule, the firm selected for final engineering design, and other variables. Therefore, final project costs are expected to vary from the cost estimates. Because of these factors, project feasibility and funding needs must be reviewed carefully before specific financial decisions are made or project budgets are established to help access proper project evaluation and adequate funding.

The cost estimates are order-of-magnitude estimates having an intended accuracy range of +30 to –50 percent. The range applies only to the alternatives as they are defined in Section 4 and does not account for changes in the scope of the alternatives. Selection of specific technologies or processes to configure remedial alternatives is not intended to limit flexibility during remedial design, but rather to provide a basis for preparing cost estimates. The specific details of remedial actions and cost estimates would be refined during the final design stage.

## **5.2 INDIVIDUAL ANALYSIS OF ALTERNATIVES**

The detailed evaluation of each alternative weighed against seven of the nine NCP evaluation criteria is presented below.

### **5.2.1 Alternative 1: No Further Action**

#### ***1. Overall protection of human health and the environment***

Currently concentrations of certain COCs in groundwater are above the cleanup standards. Alternative 1 does not remove COCs from groundwater and could allow impacted groundwater to move off site. The site-related COCs are expected to persist in groundwater at concentrations exceeding the cleanup standards because of the COC mass stored in the low-permeability zones. The groundwater quality beneath the site is also influenced by the inflow

of impacted groundwater from upgradient sources. Because of this complication, it is not possible to confidently estimate the time required to reach the cleanup standards for site groundwater. It is expected that land use restrictions are needed to protect human health for on-site residents or workers for at least several decades. This alternative does not address the risk associated with long-term exposure through the vapor intrusion pathway. However, the current building conditions are protective of vapor intrusion (Water Board, 2009a). If the use of the site changes in the future, vapor intrusion concerns can be addressed through engineering control and building design (DTSC, 2009).

## **2. Compliance with ARARs**

Natural attenuation processes and proper management of chemicals in the region are expected to reduce COC concentrations below ARARs. However, it could take several more decades.

## **3. Long-term effectiveness and permanence**

The risk reduction is expected to be very slow because no further action will be taken to remove COCs in the aquifer system. Continuation of the current land use control measures is necessary to help achieve human health protection. The remedy does not address the risk associated with long-term exposure through the vapor intrusion pathway because concentrations for some COCs in groundwater may remain above the semi-site-specific screening levels developed in Appendix C.

## **4. Reduction of toxicity, mobility, or volume through treatment**

This alternative does not involve any treatment process. The reduction of toxicity, mobility, and volume of COCs is expected to occur at a slower rate through natural attenuation processes. Natural degradation of COCs is considered to be an irreversible process.

## **5. Short-term effectiveness**

This alternative is not expected to reduce risk substantially in the short term, because of the long time frame associated with natural attenuation processes. Because this alternative does not involve any remedial action, there is no health or environmental concern related to construction and implementation of the remedy.

## **6. Implementability**

No implementability issues have been identified for this alternative.

## **7. Cost**

The estimated capital and annual O&M costs for this alternative are \$0 and \$0, respectively.

### **5.2.2 Alternative 2: Groundwater Extraction and Treatment (1991 ROD)**

#### **1. Overall protection of human health and the environment**

Alternative 2 is the current approved remedy for the site, selected by the Water Board and the

U.S. EPA in 1991. The remedy can effectively establish hydraulic control of impacted groundwater and prevent COCs from moving off site, thereby protecting the environment in the downgradient area. This alternative appeared to not be effective in reducing COC concentrations in groundwater to levels below cleanup goals, as evidenced by a gradual decrease in efficiency in removing the VOC mass through the GWET system (Water Board, 1996).

The site-related COCs are expected to persist in groundwater at concentrations exceeding the cleanup standards because of both the COC mass stored in the low-permeability zones and the impact of off-site upgradient sources. However, because the ISB program implemented between 2005 and 2011 has greatly reduced the COC concentrations in the suspected source area near DW-1 and DW-2, this alternative may become more effective. Although it is not possible to confidently estimate the time required to reach the cleanup standards for site groundwater because of complex site conditions, it is expected that the time required to achieve ambient groundwater conditions using this alternative will be noticeably shorter than for Alternative 1.

Alternative 2 does reduce the risk associated with long-term exposure through the vapor intrusion pathway, since COC concentrations in groundwater will decrease through flushing to the ambient levels, which are generally below the semi-site-specific screening levels for commercial and industrial land use (Appendix C).

Land use restrictions are necessary for protecting human health for on-site workers and hypothetical future residents. This alternative does not directly address the vapor intrusion concerns. The current building conditions are protective of vapor intrusion (Water Board, 2009a). If the use of the site changes in the future, vapor intrusion concerns can be addressed through engineering control and building design (DTSC, 2009).

## ***2. Compliance with ARARs***

Enhanced flushing through groundwater extraction, natural attenuation processes, and proper management of chemicals in the region is expected to reduce COC concentrations below ARARs. However, it may take several decades. Collected groundwater may need to be specially handled to meet ARARs associated with treatment, storage, recycle, and/or disposal of hazardous wastes.

## ***3. Long-term effectiveness and permanence***

The risk reduction is expected to be accelerated by enhanced groundwater extraction and COC removal. Continuation of the current land-use control measures is necessary to help achieve human health protection. Although the remedy does not directly address the risk associated with long-term exposure through the vapor intrusion pathway, historical performance monitoring at the site indicates that extensive pumping tends to reduce COC

concentrations in groundwater; therefore, it may reduce the potential for vapor intrusion except where COCs from offsite sources may be impacting the groundwater beneath the site.

#### **4. Reduction of toxicity, mobility, or volume through treatment**

This alternative provides adequate mobility control through hydraulic containment. The historical concentration trends provided in Table 7a and on Figures 5a through 5c suggest that groundwater extraction can significantly reduce COC concentrations in groundwater in the beginning, but can become ineffective later on. The concentration reduction is expected to eventually be controlled by ambient conditions. Groundwater extraction did not reduce the extent of the COC distribution during the GWET operations, partly because of the COC mass stored in the low-permeability zones, but it would reduce mobility of COCs by hydraulic containment.

#### **5. Short-term effectiveness**

This alternative is expected to slightly reduce risk initially as concentrations of COCs decrease, although risk reduction will slow as concentrations reach asymptotic states. During implementation, risks to workers can be minimized if proper health and safety procedures are followed. If additional remedial construction is required, workers must adhere to the health and safety plan to minimize exposure to soil contaminants during well installation. During remedial operations, risks to workers are limited to the normal safety-related risks associated with those operations. Health- and safety-related risks to the community are expected to be minimal. Environmental impacts during remedial operations are limited to the minor truck traffic and air emissions from the air stripper system; this impact should be minimal with appropriate air emission controls and negligible if GAC treatment were used as an alternative to air-stripping. Discharge of treated groundwater would comply with the requirements specified on the site NPDES permit to minimize environmental impact.

#### **6. Implementability**

This remedy was previously implemented at the site. Necessary engineering services and materials are readily available to restart the GWET system. The site previously held a NPDES permit, allowing discharge of treated water at a maximum rate of 70 gpm. There is no known impediment to obtain a new NPDES permit.

#### **7. Cost**

The estimated capital and annual O&M costs for this alternative are \$0 and \$115,000, respectively.

### **5.2.3 Alternative 3: Monitored Natural Attenuation in the A Zone and Groundwater Extraction and Treatment in the B Zones**

#### **1. Overall protection of human health and the environment**

Alternative 3 is expected to achieve a level of protection of human health and the environment

similar to that attained by Alternative 2. The potential for human exposure will be minimized primarily through the land-use control measures already implemented at the site. The MNA component is expected to have little impact on the overall protection of human health and the environment.

## ***2. Compliance with ARARs***

Enhanced flushing through groundwater extraction, natural attenuation processes, and proper management of chemicals in the region is expected to reduce COC concentrations below ARARs. However, it may take several decades, similar to or slightly longer than the time required for Alternative 2. Collected groundwater may need to be specially handled to meet ARARs associated with treatment, storage, recycle, and/or disposal of hazardous wastes.

## ***3. Long-term effectiveness and permanence***

The risk reduction is expected to be accelerated by enhanced groundwater extraction and COC removal. Continuation of the current land-use control measures is necessary to help achieve human health protection. Although the remedy does not directly address the risk associated with long-term exposure through the vapor intrusion pathway, groundwater extraction in the B zones may enhance the flushing in the A zone and reduce the extent of back diffusion of COCs from the low permeability zones in contact with the base of the A zone, thereby reducing COC concentrations in the A zone gradually.

## ***4. Reduction of toxicity, mobility, or volume through treatment***

This alternative provides adequate mobility control for the B zones through hydraulic containment. The historical concentration trends provided in Table 7a and on Figures 5a through 5c suggest that groundwater extraction can significantly reduce COC concentrations in groundwater in the beginning, but can become ineffective later on. The concentration reduction is expected to eventually be controlled by ambient conditions. Groundwater extraction did not reduce the extent of the COC distribution during the GWET operations, partly because of the COC mass stored in the low-permeability zones.

Remediation of the A zone will depend on the extent of the natural attenuation processes. The following physical and biological processes are expected to be the primary drivers for toxicity, mobility, and volume reduction: (1) microbial activity stimulated during the ISB implementation may continue degrading COCs in the A zone; (2) COCs in the A zone will be captured by the extraction wells in the B zones due to the leaky nature of the low-permeability zones; and (3) COC concentrations will decrease to the ambient levels due to flushing of ambient groundwater.

## ***5. Short-term effectiveness***

Similar to Alternative 2, this alternative is expected to reduce risk initially as concentrations of COCs decrease. However, risk to receptors will not decrease as significantly as for Alternative

2, since the A zone is not specifically targeted. Risks to workers can be minimized if proper health and safety procedures are followed. If additional remedial construction is required, workers must adhere to the health and safety plan to minimize exposure to soil contaminants during well installation. During remedial operations, risks to workers are limited to the normal safety-related risks associated with these operations. Health- and safety-related risks to the community are expected to be minimal. Environmental impacts during remedial operations are limited to the minor truck traffic and air emissions from the air stripper system; this impact should be minimal with appropriate air emission controls or negligible if GAC is used instead of air-stripping. Discharge of treated groundwater would comply with the requirements specified on the site NPDES permit to minimize environmental impact.

### **6. Implementability**

This remedy was previously implemented at the site. Necessary engineering services and materials are readily available to restart the GWET system. The site previously held a NPDES permit, allowing discharge of treated water at a maximum rate of 70 gpm. There is no known impediment to obtain a new NPDES permit.

### **7. Cost**

The estimated capital and annual O&M costs for this alternative are \$0 and \$102,000, respectively.

## **5.2.4 Alternative 4: In Situ Bioremediation and Monitored Natural Attenuation**

### **1. Overall protection of human health and the environment**

Alternative 4 is the remedy currently used to accelerate site cleanup. As demonstrated in Appendix D, the time required to reach cleanup standards depends on the effectiveness of a remedy to remove COCs from the low-permeability zones. This alternative is effective in reducing COC concentrations in groundwater, as evidenced by low COC concentrations at DW-1 and DW-2, near a known COC source area, without significant rebound after the ISB implementation (Figures 4a and 4b). This also suggests that the ISB treatment is able to readily reduce COC concentrations to the levels below the ambient groundwater conditions and even achieve cleanup goals in a reasonable time frame. However, the off-site upgradient sources will limit the effectiveness of the ISB treatment (and any other remedy that does not involve upgradient treatment) to some extent.

Although it is not possible to confidently estimate the time required to reach the cleanup standards for site groundwater because of complex site conditions, it is expected that the time required to achieve ambient groundwater conditions using this alternative will be noticeably shorter than for other alternatives. Land use restrictions are needed to protect human health for on-site workers or potential future residents. This alternative is expected to effectively reduce the COC concentrations below the semi-site-specific screening levels presented in Table D-3 in Appendix D, thereby mitigating vapor intrusion exposure.

## **2. Compliance with ARARs**

ISB treatment, natural attenuation processes, and proper management of chemicals in the region is expected to reduce COC concentrations below ARARs. Although the ISB has a great potential to meet ARARs at the site within a reasonable time frame, continued ISB treatment may be needed to mitigate the influences from the off-site upgradient sources.

## **3. Long-term effectiveness and permanence**

The risk reduction is expected to be accelerated by ISB. Continuation of the current land-use control measures is necessary to help achieve human health protection before microbial reactions reduce COC concentrations to the levels below the cleanup standards. The time required to reach the cleanup standards using this alternative may be significantly shorter than for other alternatives.

## **4. Reduction of toxicity, mobility, or volume through treatment**

This alternative can provide adequate mobility control through groundwater recirculation and microbial degradation. Judging by the concentration trends collected during the ISB implementation period (Figures 4a through 4c), the ISB can be expected to greatly reduce the toxicity, mobility, and volume of impacted groundwater.

## **5. Short-term effectiveness**

This alternative has the highest ability to reduce risk in the short term, as active ISB can quickly decrease concentrations of COCs in groundwater. During implementation, risks to workers can be minimized if proper health and safety procedures are followed. If additional remedial construction is required, workers must adhere to the health and safety plan to minimize exposure to soil contaminants during well installation. During remedial operations, risks to workers are limited to normal safety-related risks associated with those operations. Health- and safety-related risks to community are expected to be minimal. Environmental impacts during remedial operations are limited to the minor truck traffic.

## **6. Implementability**

This remedy is being used at the site, and the ISB system is currently under the passive monitoring mode. Necessary engineering services and materials are readily available for restart or expansion of in situ bioremediation.

## **7. Cost**

The estimated capital and the largest annual O&M costs for this alternative are \$0 and \$151,000, respectively.

### **5.2.5 Alternative 5: Permeable Reactive Barrier**

#### **1. Overall protection of human health and the environment**

The level of protection of human health and the environment for Alternative 5 is similar to that of Alternatives 2 and 3. The impacts of site-related COCs will be limited within the site



boundary, and cleaned groundwater will flush the aquifer system downgradient of the site. The groundwater quality within the site boundary will improve gradually due to the exhaustion of COC mass stored in the low-permeability zones. Land use restrictions will be the primary means of protecting human health for on-site workers or potential future residents from impacted groundwater. This alternative does not directly address the vapor intrusion concerns. The current building conditions are protective of vapor intrusion (Water Board, 2009a). If the use of the site changes in the future, vapor intrusion concerns can be addressed through engineering control and building design (DTSC, 2009).

## ***2. Compliance with ARARs***

The PRB alternative is expected to treat impacted groundwater passing through the reactive columns to levels below the cleanup standards. However, the time required for achieving ARARs for impacted groundwater at the site also depends on the desorption rate of COCs from the low-permeability zones. In addition, the influence from the off-site upgradient sources will probably dictate the actual time that it takes to achieve ARARs for the whole site. Natural attenuation processes and proper management of chemicals in the region are expected to reduce COC concentrations in groundwater below ARARs.

## ***3. Long-term effectiveness and permanence***

The primary risk reduction achieved by this alternative is preventing COCs from moving off site. Residual risks will be eliminated once COC concentrations decrease to below the cleanup standards. The time required to reach the cleanup goals upgradient of the PRB is expected to be similar to that of Alternative 1, and may depend on the ambient groundwater quality in the upgradient area of the site. Cleanup goals would be reached downgradient of the PRB in a more timely manner.

## ***4. Reduction of toxicity, mobility, or volume through treatment***

Alternative 5 can provide adequate mobility control to prevent the advective movement of COCs off site. COC concentrations in impacted groundwater will be reduced to the levels below the cleanup standards in the PRB. The volume of impacted groundwater upgradient of the PRB is expected to decrease at a much slower rate than with the ISB approach because COC degradation occurs only in the PRB.

## ***5. Short-term effectiveness***

The primary risk reduction achieved by this alternative is preventing COCs from moving off site. This reduction is expected to be immediate, as abiotic process to dechlorinate VOCs is rapid. However, risks to receptors at the site are not expected to see a decrease in the short term because rates of desorption and natural attenuation are slow. Risks to workers can be minimized if proper health and safety procedures are followed. The remedial construction requires workers to follow the health and safety plan to minimize exposure to COCs in soil and groundwater during soil column construction. Health- and safety-related risks to the community

are expected to be minimal. Environmental impacts during remedial operations are limited to the minor truck traffic.

### **6. Implementability**

Because of space constraints at the site, the PRB system for the site will be a network of reactive soil columns rather than a continuous reactive wall. This type of PRB has been applied to a nearby site. Necessary engineering services and materials are readily available to construct the PRB.

### **7. Cost**

The estimated capital and O&M costs for this alternative are \$1,965,000 and \$60,000, respectively.

## **6.0 COMPARATIVE ANALYSIS OF ALTERNATIVES**

In Section 5.0, the remedial alternatives were evaluated with respect to the seven evaluation criteria, which are set forth in the NCP and accompanying U.S. EPA guidance (U.S. EPA, 1988). A comparative analysis of the performance of each of the alternatives with respect to the seven evaluation criteria specified in the NCP was made. The results of this comparison are presented in Table 15. The comparative analysis indicates that Alternative 4 is the most effective approach to accelerating site cleanup because it is capable of reducing the extent and concentrations of COCs in groundwater simultaneously and of shortening remediation time by promoting COC degradation in situ, including in the low-permeability zones.

## **7.0 RECOMMENDED REMEDIAL ALTERNATIVE**

The recommended alternative is Alternative 4. Alternative 4 is recommended for implementation because it more fully satisfies the threshold criteria (overall protection of human health and the environment; compliance with ARARs) in comparison to the other alternatives. Alternative 4 also satisfies many of the balancing criteria and is comparable or outperforms other alternatives in terms of long-term effectiveness and permanence.

Implementation of Alternative 4 consists of the following components:

- ISB via substrate addition using groundwater recirculation and direct injection,
- groundwater recirculation for hydraulic control, and
- MNA when COC concentrations resemble comparable upgradient groundwater conditions.

With regard to substrate injection, the trade-off between recirculation and direct injection is the longevity and mobility of substrate. Soluble substrate is ideal for recirculation because it is easy to distribute in the transmissive zones; in contrast, direct injection is more suitable for slow-releasing substrate, which promotes microbial activity over a long period of time and permits substrate diffusion into the low-permeability zones.

The time required to achieve the cleanup standards may be prolonged because of the upgradient, offsite impacted groundwater. When COC concentrations in site groundwater resemble the ambient groundwater quality, MNA will be used to manage impacted groundwater. Additional investigation of impacted groundwater at the southern site boundary will help define the trend and extent of COCs from the upgradient sources.

In summary, it is recommended that Alternative 4 be adopted as the revised final remedy for the site. In comparison with the original remedy, the revised remedy will further accelerate site cleanup and will also provide better protection of human health and the environment.

## 8.0 REFERENCES

- AMEC Geomatrix, Inc. (AMEC), 2008, Third Five-Year Review Report, Former 901/902 Thompson Place, Sunnyvale, California, December 31.
- AMEC, 2009, Combined 2008 Annual Groundwater Monitoring and Annual In Situ Bioremediation Program Report, Former 901/902 Thompson Place, Sunnyvale, California, January 26.
- AMEC, 2011, 2010 Combined Annual Groundwater Monitoring and Annual In Situ Bioremediation Program Report, January.
- Arcadis, 2001, Five-Year Report, Advanced Micro Devices, Inc. 901/902 Thompson Place Facility, Sunnyvale, California, June.
- California Department of Water Resources (DWR), 1967, Evaluation of Groundwater Resources, South San Francisco Bay, Appendix A: Geology: DWR Bulletin 118-1.
- California Regional Water Quality Control Board, San Francisco Bay Region (Water Board), 1991, Order No. 91-102, Site Cleanup Requirements and Recision of Order No. 89-56, June 19.
- Water Board, 2004, Second Five-Year Review for the Advanced Micro Devices – 901/902 Thompson Place Superfund Site, Sunnyvale, California, September.
- Water Board, 2008a, No Further Action for Unsaturated Zone Soil at the Former AMD Facility Located at 901-902 Thompson Place, Sunnyvale, Santa Clara County, May.
- Water Board, 2008b, Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater, Interim Final, May.
- Water Board, 2009a, Third Five-Year Review for the Advanced Micro Devices – 901/902 Thompson Place Superfund Site, Sunnyvale, California, September.
- Water Board, 2009b, No Further Actions for the ICORE International, Inc., Facility, 170-180 North Wolfe Road, Sunnyvale, Santa Clara County, December.
- Water Board, 2010a, No Further Actions for the Former Pilkington Barnes Hind Facility Located at 895 Kifer Road, Sunnyvale, Santa Clara County, August.
- Water Board, 2010b, Fact Sheet on Status of Cleanup Activities for Mohawk Laboratories, 932 Kifer Road, Sunnyvale, Santa Clara County, May.

- Clement Associates, Inc., 1990, Final Baseline Health Evaluation for the AMD/Signetics/TRW Site: prepared for the California Regional Water Quality Control Board, April 12.
- Department of Toxic Substances Control (DTSC), 2009, Vapor Intrusion Mitigation Advisory, April.
- Engineering Science, Inc., 1982, Fifth Progress Report of Groundwater and Soil Sampling at AMD Buildings 901/902 and 915, October.
- Engineering Science, 1986, Groundwater Investigation at AMD Buildings 901/902 Facilities, Summary Report II, September.
- Engineering Science, 1988, Evaluation of On-Site Soil Contamination, AMD Buildings 901/902, March.
- Engineering Science, 1992, Completion of On-Site Soil Remediation at AMD Building 901, August.
- Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Prentice Hall, Inc., 604 pp.
- Freethy, G.W., Naftz, D.L., Rowland, R.C., and Davis, J.A., 2002, Deep aquifer remediation tools: Theory, design, and performance monitoring: in Naftz, D.L., Morrison, S.J., Davis, J.A., and Fuller, C.C. (eds.), Handbook of Groundwater Remediation Using Permeable Reactive Barriers, Academic Press, Elsevier Science, Chapter 5.
- Geomatrix Consultants, Inc. (Geomatrix), 2007a, In Situ Bioremediation Program Quarterly Report, September through December 2006, Former 901/902 Thompson Place Facility, Sunnyvale, California, January.
- Geomatrix, 2007b, Vapor Intrusion Assessment, 901/902 Thompson Place, Sunnyvale, California, April.
- Geomatrix, 2008, In Situ Bioremediation Program 2007 Annual Report, Former 901/902 Thompson Place Facility, Sunnyvale, California, January.
- Helley, E.J., Lajoie, K.R., Spangle, W.E., and Blair, M.L., 1979, Flatland Deposits of the San Francisco Bay Region, California: Their Geology and Engineering Properties and Their Importance to Comprehensive Planning: USGS Professional Paper 943.
- Harding Lawson Associates (HLA), 1991, Final Feasibility Study for the Companies, Sunnyvale, CA, March.
- National Research Council, 1994, Alternatives for Ground Water Cleanup, National Academy Press, 314 pp.
- Parsons Engineering Science, Inc. (Parsons ES), 1996, Five-Year Review Report for the Advanced Micro Devices, Inc. 901/902 Thompson Place Facility, June.
- Sale, T., Newell, C., Stroo, H., Hinchey, R., and Johnson, P., 2008, Frequently Asked Questions Regarding Management of Chlorinated Solvents in Soils and Groundwater, Developed for the Environmental Security Technology Certification Program (ESTCP): <http://www.serdp.org/content/download/8190/100865/version/1/file/FAQ-ChlorinatedSolvents-ER-200530.pdf>, July.
- Santa Clara Valley Water District (SCVWD), 2001, Santa Clara Valley Water District Groundwater Management Plan, July.

The Source Group, 2003, Transmittal Letter for Groundwater Flow and Contaminant Transport Modeling Report, Mohawk Laboratories, April.

United States Environmental Protection Agency (U.S. EPA), 1980, Comprehensive Environmental Response, Compensation, and Liability Act of 1980 [CERCLA, also known as Superfund].

U.S. EPA, 1988, Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, Office of Emergency and Remedial Response, EPA/540/G-89/004, OSWER Directive 9355.3-01, October.

U.S. EPA, 1990, National Oil and Hazardous Substances Pollution Contingency Plan; Final Rule: 40 CFR Part 300, Federal Register, v. 55, no. 46, p. 8666.

U.S. EPA, 1991, EPA Superfund Record of Decision: Advanced Micro Devices, Inc., EPA ID: CAD048634059, OU 01, Sunnyvale, California, September 11.

U.S. EPA, 1996, Five-Year Review for the Advanced Micro Devices (AMD) 910 Superfund Site, Sunnyvale, California, September.

U.S. EPA, 2002, OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance): EPA/530-D-02-004, November.

U.S. EPA Regions 3, 6, and 9, 2010, Regional Screening Levels for Chemical Contaminants at Superfund Sites: website, <http://www.epa.gov/reg3hwmd/risk/human/rb-concentration-table/index.htm>, November.

**TABLES**

---

**TABLE 1  
SITE CHRONOLOGY <sup>1</sup>**

Former 901/902 Thompson Place  
Sunnyvale, California

Year	Activity
1969	AMD begins semiconductor assembly at former 901 Thompson Place.
1972	AMD begins semiconductor assembly at former 902 Thompson Place.
1982	AMD discovers soil and groundwater contamination at the site. Installation of 27 groundwater monitoring wells begins; initiation of groundwater monitoring.
1983	Groundwater extraction and treatment from DW-1, DW-2, and DW-3 begins; NPDES permit is issued for discharge of treated effluent. Soil investigation at former 901 Thompson Place. Removal of former 901 Thompson Place acid neutralization system (ANS) and soil excavation.
1984	Installation of 27 groundwater monitoring wells completed. Soil investigation at former 902 Thompson Place. Removal of former 902 Thompson Place ANS and soil excavation.
1985	Monthly groundwater monitoring begins. Water Board issues Waste Discharge Requirements Order.
1986	U.S. EPA adds site to the National Priorities List.
1987	Groundwater monitoring is moved to a quarterly basis. Water Board adopts Site Cleanup Requirements order.
1988	Additional soil investigation at former 901 Thompson Place.
1989	Installation of 3 additional monitoring wells (52-, 53-DD, and 54-S). Groundwater extraction and treatment from DW-4, DW-5, and DW-6 begins. Soil gas investigation.
1990	Baseline Public Health Evaluation is completed for site.
1991	Water Board and U.S. EPA approve Final RI/FS Report and Final Remedial Action Plan (FRAP) for 901/902 Thompson Place site and adjacent TRW and Philips sites. Water Board adopts Order No. 91-102, the Final Site Cleanup Requirements for the site. U.S. EPA issues Record of Decision.
1992	AMD stops industrial operations at the site. Additional soil excavation of former 901 Thompson Place ANS.
1993	Groundwater extraction and treatment from DW-7 and DW-8 begins.
1996	Groundwater monitoring is moved to a semiannual basis.
1998	Groundwater monitoring is moved to an annual basis.
1999	Water Board and U.S. EPA complete First Five-Year Review.
2000	Adjustments are made to groundwater extraction and treatment system.
2002	Subsurface Investigation in area of former 901 Thompson Place ANS. In situ bioremediation (ISB) pilot test begins.
2004	ISB pilot test ends. Water Board and U.S. EPA complete Second Five-Year Review.
2005	Additional subsurface investigation. Full-scale ISB program begins. AMD sells the site property.
2007	Vapor intrusion report is prepared for Water Board. A single large building is constructed for use as a self-storage facility. The address is changed to 875 East Arques Avenue.
2008	Water Board approves soil remediation and grants a "No Further Action" letter for soil remediation. The full-scale ISB program is converted from an active to a passive program, where ongoing intrinsic bioremediation is monitored on a quarterly basis.
2009	Water Board and U.S. EPA complete Third Five-Year Review.

**Note**

1. Site activities from 1982 through 2000 are compiled from the Five-Year report submitted by Arcadis in 2001 and the Third Five-Year Review by the Water Board and U.S. EPA.

**TABLE 2**  
**WELL CONSTRUCTION DETAILS**  
Former 901/902 Thompson Place  
Sunnyvale, California

Well Name	Zone	Well Type	Date Completed	Ground Elevation (ft msl)	Top of Casing Elevation (ft msl)	Screen Interval (ft bgs)	Borehole Diameter (inches)	Well Diameter (inches)	Comments
14-S	A	Monitoring	3/25/1982	47.87	47.47	10-18	8	4	
15-S	A	Monitoring	3/25/1982	51.23	50.82	8-16	8	4	
16-S	A	Extraction /Monitoring	4/2/1982	47.60	47.70	9-16	8	4	
17-S	A	Monitoring	3/26/1982	46.94	46.52	8-16	8	4	
22-S	A	Monitoring	4/5/1982	46.80	46.37	11-16	8	4	
23-S	A	Monitoring	4/5/1982	47.45	47.03	9-16	8	4	
27-S	A	Monitoring	4/13/1982	50.99	50.71	9-14	8	4	
28-EX	A	Extraction	12/11/2002	47.42	47.28	10-14.3	8.5	2	
28-MW	A	Monitoring	12/11/2002	47.65	47.42	10.0-16.3	8.25	2	
28-S	A	Monitoring	4/14/1982	48.23	47.88	10-16	8	4	
29-S	A	Monitoring	4/15/1982	51.04	50.10	11-16	8	4	
36-S	A	Monitoring	6/23/1982	41.79	41.46	10-16	8	4	
37-S	A	Monitoring	6/23/1982	42.66	42.06	9-15	8	4	
38-S	A	Monitoring	6/23/1982	41.49	41.18	10-15	8	4	
DW-2	A	Monitoring/Injection	NA	48.12	46.45	10.0-14.0	NA	12	
DW-4	A	Extraction	4/18/1988	47.51	46.16	11.3-21.3	18	12	
ISB2AR	A	Extraction	3/1/2007	50.93	50.42	15.1-19.6	8.25	2	
X2A	A	Extraction/Monitoring	5/18/2005	47.20	47.08	10.0-19.9	8.25	2	
16-D	B1	Extraction/Monitoring	4/2/1982	47.70	47.49	31-41	8	4	
23-D	B1	Monitoring	April 1982	47.34	47.04	40-50	8	4	
27-D	B1	Monitoring	4/13/1982	50.98	50.59	21-31	8	4	
28-D	B1	Monitoring	4/14/1982	48.12	47.74	15-25	8	4	
29-D	B1	Monitoring	4/15/1982	51.21	50.17	21-31	8	4	
36-D	B1	Monitoring	6/24/1982	41.41	41.26	15-20	8	4	
52-D	B1	Monitoring	1989	48.75	48.31	NA	NA	NA	total depth ~50 ft
53-D	B1	Monitoring	1989	51.29	50.94	NA	NA	NA	total depth ~50 ft
DW-1	B1	Monitoring/Injection/Extraction	NA	48.15	46.91	32-40	NA	4	
DW-7	B1	Extraction/Monitoring	1992	46.99	46.10	35-45	NA	NA	
EX-01	B1	Extraction	11/8/2002	47.49	47.34	23-25	8.5	2	
ISB3BR	B1	Injection	3/1/2007	51.77	51.20	25.7-43.3	8.25	2	
MW-01	B1	Monitoring	11/8/2002	47.74	47.18	23-25	8.5	2	
PMW-1-1	B1	Monitoring	10/3/2005	47.71	47.45	26.0-27.4	5.5	1.1	
PMW-1-2	B1	Monitoring	10/3/2005	47.71	47.45	31.0-32.4	5.5	1.1	
PMW-1-3	B1	Monitoring	10/3/2005	47.71	47.45	35.9-38.5	5.5	1.1	



**TABLE 2**  
**WELL CONSTRUCTION DETAILS**  
Former 901/902 Thompson Place  
Sunnyvale, California

Well Name	Zone	Well Type	Date Completed	Ground Elevation (ft msl)	Top of Casing Elevation (ft msl)	Screen Interval (ft bgs)	Borehole Diameter (inches)	Well Diameter (inches)	Comments
PMW-2-1	B1	Monitoring	9/29/2005	47.49	47.26	26.7–28.1	5.5	1.1	
PMW-2-2	B1	Monitoring	9/29/2005	47.49	47.26	36.7–38.1	5.5	1.1	
X1B	B1	Extraction/Monitoring	5/17/2005	47.46	47.18	25.4–30.2	8.25	2	
X2B1	B1	Extraction/Monitoring	5/18/2005	47.14	46.83	26.5–36.5	8.25	2	
22-DD	B2	Monitoring	4/6/1982	46.74	46.45	43–53	8	4	
27-DD	B2	Monitoring	6/8/1982	51.03	50.72	45–55	8	4	
30-DD	B2	Monitoring	4/26/1982	47.08	46.53	40–50	8	4	
36-DD	B2	Monitoring	6/24/1982	41.82	41.58	51.5–61.5	8	4	
DW-5	B2	Monitoring	4/19/1988	47.41	46.29	38–48	18	6	
DW-6	B2	Monitoring	4/19/1988	46.56	45.53	44–49	18	6	
DW-8	B2	Extraction	NA	46.49	45.63	45–65	NA	NA	
ISB1BR	B2	Injection	2/28/2007	51.18	50.61	31.0–44.5	8.25	2	
PMW-2-3	B2	Monitoring	9/29/2005	47.49	47.26	45.5–48.2	5.5	1.1	
35-DDD	B3	Monitoring	6/8/1982	47.13	46.48	70–80	8	4	
25-S	A	Monitoring	April 1982	49.03	48.78	9.5–14	8	4	decommissioned in March 2006
26-S	A	Monitoring	4/9/1982	49.00	48.70	9–14	8	4	decommissioned in March 2006
54-S	A	Monitoring	1989	51.14	50.70	17–30	NA	NA	decommissioned in March 2006
21-S	A	Monitoring	3/26/1982	47.15	46.89	9–19	8	4	decommissioned in May 2007
P2A	A	Monitoring	9/30/2005	47.45	47.31	15.0–19.5	5.5	0.75	destroyed on August 27, 2007
I1A	A	Injection	9/6/2005	--	--	11.8–20.8	4.5	0.75	destroyed on May 2, 2006
I2A	A	Injection	9/2/2005	--	--	11.6–19.6	4.5	0.75	destroyed on May 2, 2006
DW-3	A/B1	Extraction	NA	47.78	46.51	NA	NA	NA	decommissioned in July 2007
25-D	B1	Monitoring	April 1982	48.43	47.71	19–29	8	4	decommissioned in March 2006
I1B	B1	Injection	9/6/2005	--	--	25.5–34.9	4.5	0.75	destroyed on May 2, 2006
I1B1	B1	Injection	9/2/2005	--	--	37.6–44.7	4.5	0.75	destroyed on May 2, 2006
I2B1	B1	Injection	9/1/2005	--	--	26.0–33.5	4.5	0.75	destroyed on May 2, 2006
I2B1/B2	B1	Injection	9/1/2005	--	--	35.5–39.5	4.5	0.75	destroyed on May 2, 2006
I2B22	B2	Injection	NA	--	--	44.2–48.2	4.5	0.75	destroyed on May 2, 2006

Abbreviations

-- = not applicable  
ft bgs = feet below ground surface  
ft msl = feet mean sea level  
NA = not available

**TABLE 3**

**SUMMARY OF AQUIFER PROPERTIES**

Former 901/902 Thompson Place  
Sunnyvale, California

Hydraulic Parameters Through Aquifer Testing					
Well Name	Zone	Hydraulic Conductivity	Specific Yield	Storativity	Testing Event
16-S	A	0.8	NA	NA	(a)
21-S	A	30.0	1.20E-02	1.20E-03	(b)
22-S	A	25.5	7.50E-03	1.20E-03	(b)
23-S	A	29.1	1.40E-02	1.40E-03	(b)
28-S	A	17.7	2.00E-02	5.10E-04	(b)
16-D	B1	119.7	NA	4.70E-04	(c)
23-D	B1	146.1		2.90E-03	(c)
25-D	B1	176.6		NA	(a)
27-D	B1	54.8		3.72E-04	(a)
29-D	B1	0.8*		6.72E-05	(a)
22-DD	B2	11.3		2.26E-03	(a)
30-DD	B2	27.9		NA	(a)

Notes

- (a) Short-term pump test data from August 27 to September 7, 1982
- (b) DW-1, DW-2, DW-3 pump test on February 2 and 21, 1985
- (c) DW-3 pump test on March 13 and 14, 1985

Abbreviations

- \* = estimated from transmissivity data
- NA = not available

Other Aquifer Properties				
Parameter Name	Aquifer Type	Value	Comment	Reference
Total Porosity	All	0.36	Soil data from two nearby sites: National Semiconductor Cooperation (HLA, 1991) and Mohawk Laboratory (Source Group, 2003)	HLA (1991)
Effective Porosity	TZ	0.3		Source Group (2003)
	LPZ	0.2		HLA (1991)
Bulk Density	TZ	1.9 kg/L		Source Group (2003)
	LPZ	1.48 kg/L		HLA (1991)
foc	All	0.002		Source Group (2003)

Abbreviations

- foc = fraction of organic carbon in soil
- kg/L = kilograms per liter
- LPZ = low-permeability zone (fine-grained portion of the aquifer)
- TZ = transmissive zone (coarse-grained portion of the aquifer)

**TABLE 4**  
**ANALYTICAL RESULTS FOR GROUNDWATER SAMPLES <sup>1,2</sup>**  
**OCTOBER 2010**

Former 901/902 Thompson Place  
Sunnyvale, California

Results reported in micrograms per liter (µg/L)

Well ID	Aquifer Zone	Sampling Date	PCE	TCE	cDCE	tDCE	VC	1,1-DCE	1,1-DCA	1,1,1-TCA	Freon 113	1,2-DCB	1,4-DCB	CB	CE	TOC
<b>A Zone Wells</b>																
15-S	A	10/26/2010	<0.5 <sup>3</sup>	11 <sup>4</sup>	9.3	<0.5	<0.5	<0.5	<0.5	<0.5	<2.0	<0.5	<0.5	<0.5	<1.0	-
16-S	A	10/21/2010	<0.5	<0.5	6.9	6.4	21	<0.5	<0.5	<0.5	<2.0	13	2.1	13	2.9	6.4
22-S	A	10/28/2010	<0.5	16	25	12	2.4	<0.5	<0.5	<0.5	<2.0	30	1.6	8.5	<1.0	-
23-S	A	10/21/2010	<1.3	9.5	350	19	160	<1.3	<1.3	<1.3	<5.0	18	<2.5	1.6	<2.5	2.7
27-S	A	10/28/2010	17	300	79	<2.5	<2.5	<2.5	<2.5	<2.5	<10	<2.5	<2.5	<2.5	<5.0	-
27-S (Dup)	A	10/28/2010	17	290	76	2.6	<2.5	<2.5	<2.5	<2.5	<10	<2.5	<2.5	<2.5	<5.0	-
28-S	A	10/28/2010	<0.5	<0.5	6.1	6.6	77	<0.5	<0.5	<0.5	<2.0	14	0.9	2.7	<1.0	-
29-S	A	10/25/2010	<0.5	18	1.6	<0.5	<0.5	<0.5	<0.5	0.7	<2.0	<0.5	<0.5	<0.5	<1.0	-
36-S	A	10/28/2010	2.0	75	11	0.6	<0.5	0.5	<0.5	0.7	<2.0	<0.5	<0.5	<0.5	<1.0	-
37-S	A	10/28/2010	0.9	60	3.7	<0.5	<0.5	<0.5	<0.5	<0.5	<2.0	<0.5	<0.5	<0.5	<1.0	-
28-MW	A	10/21/2010	<0.5	<0.5	10	1	73	<0.5	<0.5	<0.5	<2.0	6.2	0.6	8.1	2.2	5.1
DW-2	A	10/21/2010	<0.5	<0.5	1.1	0.9	<0.5	<0.5	<0.5	<0.5	<2.0	0.7	<0.5	<0.5	<1.0	23
X2A	A	10/21/2010	<0.5	<0.5	13	<0.5	850	<0.5	<0.5	<0.5	<2.0	13	<5.0	22	<10	4.2
<b>B1 Zone Wells</b>																
16-D	B1	10/21/2010	<1.7	<1.7	180	14	180	<1.7	<1.7	<1.7	<6.7	6.6	<1.7	5.2	<3.3	1.9
23-D	B1	10/21/2010	<2.5	160	360	20	52	3.5	<2.5	<2.5	<10	7.5	<2.5	3	<5.0	1.2
23-D (Dup)	B1	10/21/2010	<2.0	150	350	19	54	2.8	<2.0	<2.0	<8.0	7.6	<2.0	2.7	<4.0	1.3
27-D	B1	10/26/2010	4.9	110	1.9	<1.0	<1.0	<1.0	<1.0	1.0	<4.0	<1.0	<1.0	<1.0	<2.0	-
27-D (Dup)	B1	10/26/2010	5.0	110	1.7	<1.0	<1.0	<1.0	<1.0	1.1	<4.0	<1.0	<1.0	<1.0	<2.0	-
28-D	B1	10/26/2010	<0.5	1.5	15	6.2	90	<0.5	<0.5	<0.5	<2.0	3.8	0.5	5.6	4.3	-
29-D	B1	10/26/2010	1.6	35	1.5	<0.5	<0.5	<0.5	<0.5	0.6	<2.0	<0.5	<0.5	<0.5	<1.0	-
36-D	B1	10/28/2010	1.4	47	34	1.2	<0.5	0.7	<0.5	<0.5	<2.0	<0.5	<0.5	<0.5	<1.0	-
52-D	B1	10/26/2010	<0.5	35	1.8	<0.5	<0.5	0.6	<0.5	0.9	<2.0	<0.5	<0.5	<0.5	<1.0	-
53-D	B1	10/25/2010	<0.5	6.9	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<2.0	<0.5	<0.5	<0.5	<1.0	-
PMW-2-1	B1	10/21/2010	<42	79	6800	54	1800	<42	<42	<42	<170	<42	<42	<42	<83	1.6
DW-1	B1	10/21/2010	<0.5	0.6	1.2	10	3.1	<0.5	<0.5	<0.5	<2.0	0.7	<0.5	2.6	<1.0	23

**TABLE 4**  
**ANALYTICAL RESULTS FOR GROUNDWATER SAMPLES <sup>1,2</sup>**  
**OCTOBER 2010**  
Former 901/902 Thompson Place  
Sunnyvale, California

Results reported in micrograms per liter (µg/L)

Well ID	Aquifer Zone	Sampling Date	PCE	TCE	cDCE	tDCE	VC	1,1-DCE	1,1-DCA	1,1,1-TCA	Freon 113	1,2-DCB	1,4-DCB	CB	CE	TOC
DW-7	B1	10/21/2010	<1.0	<b>5.2</b>	<b>52</b>	<b>2.1</b>	<b>140</b>	<1.0	<1.0	<1.0	<4.0	<1.0	<1.0	<1.0	<2.0	<b>0.8</b>
X1B	B1	10/21/2010	<8.3	<b>240</b>	<b>2400</b>	<b>32</b>	<b>49</b>	<b>12</b>	<8.3	<8.3	<33	<8.3	<8.3	<8.3	<17	<b>1.3</b>
X2B1	B1	10/21/2010	<7.1	<b>59</b>	<b>470</b>	<b>13</b>	<b>690</b>	<7.1	<7.1	<7.1	<29	<7.1	<7.1	<7.1	<14	<b>1.1</b>
<b>B2 Zone Wells</b>																
22-DD	B2	10/28/2010	<0.6	<b>97</b>	<b>78</b>	<b>3.8</b>	<b>25</b>	<b>0.9</b>	<0.6	<0.6	<2.5	<b>1.9</b>	<0.6	<0.6	<1.3	-
27-DD	B2	10/28/2010	<b>2.3</b>	<b>59</b>	<b>3.9</b>	<0.5	<0.5	<0.5	<0.5	<0.5	<2.0	<0.5	<0.5	<0.5	<1.0	-
36-DD	B2	10/26/2010	<0.5	<0.5	<b>14</b>	<b>0.7</b>	<b>2.2</b>	<0.5	<0.5	<0.5	<2.0	<0.5	<0.5	<0.5	<1.0	-
PMW-2-3	B2	10/21/2010	<1.7	<b>260</b>	<b>220</b>	<b>5.8</b>	<b>21</b>	<1.7	<1.7	<1.7	<6.7	<1.7	<1.7	<1.7	<3.3	<b>0.51</b>
<b>B3 Zone Well</b>																
35-DDD	B3	10/25/2010	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<2.0	<0.5	<0.5	<0.5	<1.0	-

#### Notes

- Groundwater samples were collected by Field Solutions, Inc., of San Jose, California, and analyzed by Curtis & Tompkins, Ltd., of Berkeley, California, for the U.S. EPA Method 8010 list with Freon 113 in accordance with U.S. EPA Method 8260B.
- Only compounds regulated by Order 91-102 are included in this table; for a full list of analytes and detected compounds, see laboratory analytical reports.
- "<" indicates constituent was not detected above the laboratory reporting limit shown.
- Results in **bold** indicate that the constituent was detected in the sample above the laboratory reporting limit.

#### Abbreviations

1,1-DCE = 1,1-dichloroethene	Freon 113 = 1,1,2-trichloro-1,2,2-trifluoromethane
1,1-DCA = 1,1-dichloroethane	PCE = tetrachloroethene
1,1,1-TCA = 1,1,1-trichloroethane	TCE = trichloroethene
1,2-DCB = 1,2-dichlorobenzene	tDCE = trans-1,2-dichloroethene
cDCE = cis-1,2-dichloroethene	VC = vinyl chloride
Dup = duplicate sample	

TABLE 5a

DOCUMENTED TCE GROUNDWATER SOURCES THAT POTENTIALLY IMPACT THE SITE <sup>1</sup>

Former 901/902 Thompson Place  
Sunnyvale, California

Results reported in micrograms per liter (µg/L)

Site Name	Site Number	Distance to former 901/902 Thompson Place	Type of Industry	When Industrial Operation Began	When GW Monitoring/ Extraction Began	Site Status <sup>2</sup>	Historical Maximum PCE Conc. <sup>3</sup>	Historical Maximum TCE Conc. <sup>3</sup>	Historical Maximum cDCE Conc. <sup>3</sup>
<b>South-Southwest or Southwest of the Site</b>									
ICORE International	SL0608532554	2,000 feet	Electrical harness assemblies	1971	1999	Closed	<b>57</b>	<b>350</b>	<b>280</b>
Royal Auto Body	T0608564059	2,800 feet	Analytical labs	1960s	2005	Open	<b>6.4</b>	<b>541</b>	<b>330</b>
Magnetics, Inc.	SLT20340230	2,800 feet	Photo etching facility	1968	2005	Open	<b>83.9</b>	<b>1,300</b>	<b>1.04</b>
Philips Semiconductor (Kifer)	SL18346766	3,000 feet	Semiconductors	1970	1983	Closed	<b>74</b>	<b>1,400</b>	<b>52</b>
<b>South of the Site</b>									
Mohawk Laboratories	SL20201820	4,000 feet	Analytical Labs	mid-1950s	1993	Open	<b>&gt;10,000</b> <sup>4, 5</sup>	<b>&gt;10,000</b>	<b>&gt;10,000</b>
Pilkington Barnes Hind	SL18207587	3,100 feet	Contact lens manufacturing	earlier than late 1980s	1994	Closed	<b>91</b>	<b>5,100</b>	<b>91</b>

Notes

1. Data obtained from the GEOTRACKER website maintained by the California State Water Resources Control Board:  
<http://geotracker.waterboards.ca.gov/>.
2. Open = under remediation; Closed = no further action.
3. Historical maximum concentration in the A zone.
4. ">" indicates constituent detected above the level shown.
5. Results in **bold** indicate the constituent was detected in the sample above the laboratory reporting limit.

Abbreviations

cDCE = cis-1,2-dichloroethene  
PCE = tetrachloroethene  
TCE = trichloroethene

TABLE 5b

VOC CONCENTRATIONS RECENTLY DETECTED AT UPGRADIENT SITES IN THE A ZONE <sup>1</sup>

Former 901/902 Thompson Place  
Sunnyvale, California

Results reported in micrograms per liter (µg/L)

Site Name	Site Status	Monitoring Well Name	Distance to former 901/902 Thompson Place	Sampling Year	PCE	TCE	cDCE
ICORE International <sup>2</sup>	Closed	--	2,000 feet	2009	<b>27</b> <sup>3</sup>	<b>74</b>	<b>1.6</b>
Royal Auto Body	Open	RMW-1	2,800 feet	2010	<b>2.8</b>	<b>98</b>	<b>93</b>
Magnetics, Inc.	Open	MW-2	2,800 feet	2010	<b>58.6</b>	<b>882</b>	<10 <sup>4</sup>
Philips Semiconductor (Kifer)	Open	S102A	3,000 feet	2009	< 1.3	<b>180</b>	<b>13</b>
Pilkington Barnes Hind <sup>2</sup>	Closed	--	3,100 feet	2008	<2.5–19	<b>110 - 230</b>	<0.5
<b>Monitoring Wells at the Upgradient Area of the AMD 901/902 and Philips Signetics Sites</b>							
Philips (Signetics)	Open	S157A	--	2010	<b>0.9</b>	<b>59</b>	<b>1.6</b>
		S084A		2004	<b>4.9</b>	<b>71</b>	<b>1.9</b>
AMD 901/902	Open	15-S	--	2010	<0.5	<b>11</b>	<b>9.3</b>
		29-S			<0.5	<b>18</b>	<b>1.6</b>

Notes

1. The A aquifer is the shallowest aquifer.
2. Data adopted from the No Further Action letter issued by the Water Board.
3. Results in **bold** indicate the constituent was detected in the sample above the laboratory reporting limit.
4. "<" indicates constituent not detected above the laboratory reporting limit shown.

Abbreviations

cDCE = cis-1,2-dichloroethene  
PCE = tetrachloroethene  
TCE = trichloroethene  
VOC = volatile organic compounds

TABLE 6a

**HISTORICAL GROUNDWATER EXTRACTION RATES AND VOC REMOVAL AND EFFICIENCY <sup>1</sup>**

Former 901/902 Thompson Place  
Sunnyvale, California

Year	Volume Extracted <sup>1</sup> (gallons)	Average Influent VOCs Concentration (µg/L)	Average Annual Extraction Rate (gpm)	Estimated Total VOCs Removed (pounds)	Extraction System Efficiency (lb/MG)
Historical Groundwater Extraction					
1984-1995 <sup>2,3</sup>	126,940,000	529	20.13	559	4.4
1996	16,140,000	283	30.62	38	2.4
1997	15,817,920	339	30.09	45	2.8
1998	16,636,170	277	31.65	38	2.3
1999	16,170,000	251	30.76	33	2.0
2000	12,291,830	262	23.32	27	2.2
2001	13,032,970	281	24.80	29	2.2
2002	13,495,145	363	25.68	40	2.9
<b>Subtotals/Average <sup>3</sup></b>	<b>230,524,035</b>	<b>414</b>	<b>23.08</b>	<b>809</b>	<b>--</b>
ISB Groundwater Extraction					
2006	586,929	1,287	1.12	5.9	10.0
2007	154,649	2,653	0.29	3.0	19.5
2008	261,553	505	0.50	1.3	4.4
<b>Subtotals/Average <sup>3</sup></b>	<b>1,003,131</b>	<b>1482</b>	<b>0.64</b>	<b>10</b>	<b>--</b>
<b>Total <sup>3</sup></b>	<b>231,527,166</b>	<b>7,031</b>	<b>--</b>	<b>819</b>	<b>--</b>

Notes

1. The extraction volumes (and associated VOCs removed estimate) are based on meter readings for individual extraction
2. Estimated values.
3. Mass removed values rounded to nearest pound; averaging applied to influent concentration and extraction rate.

Abbreviations

-- = not calculated  
µg/L = micrograms per liter  
ISB = in situ bioremediation  
lb/MG = pounds VOCs removed per million gallons extracted  
VOCs = volatile organic compounds

**TABLE 6b**

**REPRESENTATIVE ANNUAL PUMPING RATES**

Former 901/902 Thompson Place  
Sunnyvale, California

Year	Well Name	Zone	Representative Extraction Rate (gpm)
<b>1995</b> <sup>1</sup>	DW-1	B1	2.83
	DW-2	A	0
	DW-3	A/B1	7.52
	DW-4	A	0.88
	DW-5	B2	0.04
	DW-6	B2	7.96
	DW-7	B1	2.03
	DW-8	B2	12.54
<b>2000/2001</b> <sup>1</sup>	DW-1	B1	2.91
	DW-2	A	0
	DW-3	A/B1	6.97
	DW-4	A	0.56
	DW-5	B2	0.80
	DW-6	B2	3.87
	DW-7	B1	1.38
	DW-8	B2	7.46
<b>2006 (ISB)</b> <sup>2</sup>	X2B1	B1	0.59
	X2A	A	0.31
	X1B	B1	0.71
	16-S	A	0.4
	DW-7	B1	0.79
	DW-8	B2	0.5
	16-D	B1	0.52
<b>2007 (ISB)</b> <sup>3</sup>	DW-1 / ISB1BR	B1 / B2	0.6
	DW-1 / ISB2BR	B1	0.6
	DW-1 / ISB3BR	B1	0.5
	ISB2AR / ISB1AR	A	0.2
<b>2008 (ISB)</b> <sup>4</sup>	X2A, 16-S / DW-2	A	0.7
	DW-1 / ISB2BR	A / B1	0.8
	X1B, X2B1, 16-D, DW-7 / DW-1	B1	1

**Notes**

1. Years 1995 and 2000/2001 average flow rates are based on the Second Five-Year Report (Arcadis, 2001).
2. Year 2006 average flow rate is calculated from Table 2 of the In Situ Bioremediation Program Quarterly Report (Geomatrix Consultants, Inc., 2007a).
3. Year 2007 average flow rate is from Table 3 of the In Situ Bioremediation Program 2007 Annual Report (Geomatrix Consultants, Inc., 2008).
4. Year 2008 average flow rate is from Table 9 of the Combined Annual Groundwater Monitoring and Annual In Situ Bioremediation Program Report (AMEC, 2009).



TABLE 7a

**TRENDS OF TCE CONCENTRATION CHANGE AT SELECTED WELLS**

Former 901/902 Thompson Place  
Sunnyvale, California

Results reported in micrograms per liter (µg/L)

Well Name	Zone	TCE Concentration Change <sup>1</sup>		
		GWET Operation Period (1982–1992)	GWET Operation Period (1992–2002)	ISB Operation Period (2005–2008)
16-S	A	from 3,000 to 50	from 50 to 40	from 43 <sup>2</sup> to <0.5
22-S	A	from 6,000 to 110	from 110 to 30	from 190 to 7.8
23-S	A	from 3,000 to 15	from 15 to 10	from 33 to 29
28-S	A	from 30,000 to 110	from 110 to 330	from 330 <sup>2</sup> to 1.6
16-D	B1	from 3,000 to 200	from 200 to 130	from 110 to <1.7
23-D	B1	from 3,000 to 1,000	from 1,000 to 200	from 110 to 8
28-D	B1	from 30,000 to 130	from 130 to 290	from 160 to 0.9

Note

1. Representative TCE concentrations used for the beginning and end of specified periods.
2. October 2002 data used as beginning of ISB period because well was in initial pilot test zone of influence.

TABLE 7b

**TRENDS OF CHLORINATED ETHENE CONCENTRATIONS AT  
SELECTED WELLS**

Former 901/902 Thompson Place  
Sunnyvale, California

Results reported in micrograms per liter (µg/L)

Well Name	Zone	Total Concentration of Chlorinated Ethenes (PCE+TCE+cDCE+VC)		Percentage of Soluble Products <sup>1</sup> (cDCE+VC) / (PCE+TCE+cDCE+VC)	
		Before ISB Operation (October 2005)	After ISB Operation (October 2008)	Before ISB Operation (October 2005)	After ISB Operation (October 2008)
16-S	A	67	8	96%	100%
22-S	A	380	60	49%	87%
23-S	A	160	182	79%	84%
28-S	A	74	17	66%	91%
X2A	A	494	895	59%	100%
DW-1	B1	35,032	44	49%	94%
DW-7	B1	405	277	26%	94%
X1B	B1	2,100	1,272	82%	96%
X2B1	B1	911	590	51%	95%
16-D	B1	295	9	63%	78%
23-D	B1	215	331	49%	9.3%
28-D	B1	233	21	30%	96%

Note

1. Soluble dehalogenating products defined as cDCE and VC.

Abbreviations

cDCE = cis-1,2-dichloroethene  
PCE = tetrachloroethene  
TCE = trichloroethene  
VC = vinyl chloride

**TABLE 8**  
**GROUNDWATER CLEANUP STANDARDS**  
 Former 901/902 Thompson Place  
 Sunnyvale, California

Compound	Cleanup Goal (µg/L)
1,2-Dichlorobenzene	600
1,1-Dichloroethane	5
1,1-Dichloroethene	6
cis-1,2-Dichloroethene	6
trans-1,2-Dichloroethene	10
Freon 113	1,200
Tetrachloroethene	5
1,1,1-Dichloroethane	200
Trichloroethene	5
Vinyl chloride	0.5

Abbreviation

µg/L = micrograms per liter

**TABLE 9**

**GROUNDWATER CLEANUP STANDARDS vs.  
CURRENT U.S. EPA RISK-BASED LEVELS**

Former 901/902 Thompson Place  
Sunnyvale, California

<b>Compound</b>	<b>ROD Groundwater Cleanup Goal (µg/L)</b>	<b>Current U.S. EPA RSL for Tap Water (µg/L)</b>	<b>Risk Calculation in Excess of 10<sup>-6</sup></b>
1,2-Dichlorobenzene	600	370	$1.6 \times 10^{-6}$
1,1-Dichloroethane	5	2.4	$2.1 \times 10^{-6}$
1,1-Dichloroethene	6	340	--
cis-1,2-Dichloroethene	6	73	--
trans-1,2-Dichloroethene	10	110	--
Freon 113	1,200	NA	--
Tetrachloroethene	5	0.11	$4.5 \times 10^{-5}$
1,1,1-Trichloroethane	200	9,100	--
Trichloroethene	5	2	$2.5 \times 10^{-6}$
Vinyl chloride	0.5	0.016	$3.1 \times 10^{-5}$

Abbreviations

-- = Cleanup goal does not exceed RSL.

µg/L = micrograms per liter

NA = not available

ROD = Record of Decision

RSL = regional screening level

TABLE 10

**COMPARISON OF PROPOSED RISK-BASED CONCENTRATIONS  
AND REGULATORY SCREENING LEVELS**

Former 901/902 Thompson Place Facility  
Sunnyvale, California

Chemical	Proposed Site-Specific Risk-Based Concentration (µg/L)	CRWQCB-SF Environmental Screening Level for Groundwater (µg/L)	Risk-Based Concentration Based on RSL or ESL for Indoor Air (µg/L)
<b>Residential Land Use</b>			
PCE	28	120	28
TCE	136	530	136
cDCE	1,860	6,230	1,860
VC	4	4	5
<b>Industrial/Commercial Land Use Only</b>			
PCE	285	420	285
TCE	1,362	1,800	1,362
cDCE	5,090	17,000	5,090
VC	13	13	170

Abbreviations

cDCE = cis-1,2-dichloroethene  
ESL = environmental screening level  
µg/L = milligrams per liter  
PCE = tetrachloroethene  
RSL = regional screening level  
TCE = trichloroethene  
tDCE = trans-1,2-dichloroethene  
VC = vinyl chloride

TABLE 11a

INITIAL SCREENING OF REMEDIAL TECHNOLOGIES

Former 901/902 Thompson Place  
Sunnyvale, California

General Response Actions	Remedial Technology	Process Option	Description	Screening Comments
No Further Action	No Further Action	No Action	Required by National Contingency Plan (NCP) for purposes of comparison.	Does not meet RAOs.
Monitoring	Groundwater Sampling and Monitoring	Groundwater Sampling and Monitoring	Continue sampling and analysis of groundwater.	APPLICABLE, a necessary component for determining the performance of remedial actions.
Institutional Controls	Groundwater Use Restrictions	Access Restrictions to Groundwater	Restrict use of groundwater in contaminated areas.	APPLICABLE, a part of the ROD issued in 1991. A restrictive covenant has been placed prohibiting the use of shallow groundwater for drinking water.
Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation	Monitored Natural Attenuation of Groundwater	Conduct groundwater quality monitoring to demonstrate effectiveness of natural attenuation processes in reducing COC concentrations to acceptable levels. Additional monitoring network may required.	POTENTIALLY APPLICABLE where COC concentrations are relatively low but are higher than RAOs, and aquifer conditions favorable to natural attenuation processes have been established.
Passive Containment	Impermeable Vertical Barriers	Slurry or Sheet-Pile Wall Grout Curtain	Construct physical barrier to isolate the contaminated area and to divert groundwater migration.	NOT CONSIDERED. Remedial actions that occurred at the site have greatly reduced COC concentrations; the impermeable barriers approach would reduce natural flushing and lengthen cleanup time. It is also not implementable due to space constraint.
	Capping / Surface Water Recharge Control	Clay, Synthetic, Asphalt, Concrete, or Shotcrete Cap	Areas of concern (usually areas of impacted soil) are covered with a clay cap and protective surface cover to reduce stormwater infiltration, prevent contaminant transport, and transfer from the unsaturated to saturated zone.	NOT CONSIDERED. The site is largely paved and is covered with a layer of 5–10-foot low-permeability soil, consisting of native clay or silt. In addition, soil in the vadose zone has been properly remediated and is no longer a source for groundwater contamination.
		Surface Water Drainage Channels	System of drainage channels to control erosion and divert uncontaminated surface water runoff from infiltrating into impacted soil and/or groundwater.	NOT CONSIDERED. The site has been developed and likely complied with the city's stormwater code.
Active Containment	Contaminated Groundwater Extraction / Hydraulic Control	Groundwater Extraction	Deploy wells to extract contaminated water and to prevent the contaminant plumes from further expanding. Typically, an aboveground treatment system is used to treat extracted groundwater.	APPLICABLE, a part of the ROD issued in 1991. Less effectiveness in low hydraulic conductivity or highly heterogeneous aquifers. Groundwater extraction was performed between 1983 and 2002; however, the COC removal efficiency had reached an asymptotic level, indicating that the rate of COC removal was governed by mass transfer limitation.
		Groundwater Interceptor Trench	Deploy trenches to collect contaminated water and to prevent the contaminant plumes from further expanding. Typically an above ground treatment system is used to treat extracted groundwater.	NOT APPLICABLE, not likely to be implementable due to the depths of contaminated groundwater and current site use. The option was considered in the feasibility study completed in 1991, but was finally rejected because of its potential high cost.

TABLE 11a

INITIAL SCREENING OF REMEDIAL TECHNOLOGIES

Former 901/902 Thompson Place  
Sunnyvale, California

General Response Actions	Remedial Technology	Process Option	Description	Screening Comments
Ex Situ Groundwater Treatment: Aboveground	Physical Process	Air Stripping	Use forced air flow to transfer volatile contaminants from the aqueous phase to the gaseous phase.	APPLICABLE for treatment of volatile contaminants, a part of the ROD issued in 1991 and being used to remove VOCs from extracted groundwater.
		Liquid-Liquid Extraction	Extract contaminants based on solubility.	POTENTIALLY APPLICABLE. Likely to be more costly in comparison with other options that achieve similar results.
	Physical-Chemical Process	Carbon Adsorption	Use carbon adsorbents to remove VOCs from contaminated groundwater and air.	APPLICABLE, particularly for VOC treatment. Air-phase carbon adsorption was selected to remove VOCs from the air stripping process in the 1991 ROD. The current ISB operation at the site uses water-phase carbon adsorption to remove COCs in groundwater.
		Ion Exchange	Use ion-exchange resins to remove cations and/or anions from groundwater.	NOT APPLICABLE for VOCs.
		Oxidation	Use chemical, photo (UV), or other oxidation reactions to destroy contaminants in groundwater.	POTENTIALLY APPLICABLE. Likely to be more costly in comparison with other options that achieve similar results. Considered in the FS completed in 1991.
		Reverse Osmosis	Use high-pressure membrane to remove contaminants in groundwater.	POTENTIALLY APPLICABLE. Likely to be more costly in comparison with other options that achieve similar results. Considered in the FS completed in 1991.
	Biological Process	Aerobic / Anoxic Bioreactors	Use aerobic and facultative bacteria to degrade contaminants through cometabolism and/or respiration. Options include use of contaminants as growth substrates, secondary substrate degradation, and cometabolism.	POTENTIALLY APPLICABLE. Not likely to achieve RAOs with this option alone.
		Anaerobic Bioreactors	Use anaerobic and facultative bacteria to degrade contaminants under anoxic and strictly anaerobic conditions.	POTENTIALLY APPLICABLE. Not likely to achieve RAOs with this option alone.
In Situ Treatment	In Situ Physical Process	Thermal Treatment	Apply steam and/or hot air or heat up porous media to vaporize volatile or semivolatile compounds. On-site treatment is required to treat contaminants in vapor and water.	POTENTIALLY APPLICABLE. This option is effective for soil and shallow groundwater. In the saturated zone, effectiveness may be limited by aquifer heterogeneity and high groundwater flux.
		Air Sparging	Inject air into saturated zone to remove contaminants through volatilization.	POTENTIALLY APPLICABLE. Less effective in heterogeneous aquifers. Difficult to implement in a deep aquifer.
		Water Flushing	Inject water into the subsurface to enhance recovery of mobile dissolved COCs.	POTENTIALLY APPLICABLE under hydraulically controlled conditions. Less effective in low hydraulic conductivity or heterogeneous zones.

TABLE 11a

INITIAL SCREENING OF REMEDIAL TECHNOLOGIES

Former 901/902 Thompson Place  
Sunnyvale, California

General Response Actions	Remedial Technology	Process Option	Description	Screening Comments
In Situ Treatment	In Situ Physical Process	Cosolvent / Surfactant Flushing	Inject surfactants or cosolvents into the saturated zone to facilitate high concentration contamination removal. Good for residual NAPL recovery.	NOT APPLICABLE for remediation of VOC source areas dominated by diffusion from low K units. ISB appears to have already effectively treated the source area, so this would not be considered.
	In Situ Chemical Process	In Situ Chemical Reduction	Construct permeable reactive barriers consisting of zero valent iron (ZVI) or other chemical reducing agents (EHC) in the subsurface to initiate chemical reduction reactions.	POTENTIALLY APPLICABLE for remediation in a shallow aquifer. May require other geotechnical technologies to enhance chemical delivery.
		In Situ Chemical Oxidation	Apply oxidants to degrade contaminants. Typically, oxidants include ozone, hydrogen peroxide, sodium / potassium permanganate, and sodium persulfate.	POTENTIALLY APPLICABLE for remediation in a shallow aquifer. Less effective in low conductivity or heterogeneous aquifers.
	In Situ Biological Process	Enhanced Bioremediation	Use organic substrates to produce a biological reaction zone in which contaminants are degraded by microorganisms. There are various substrate delivery modes, including direct injection, substrate recirculation, and in situ precipitation.	APPLICABLE for remediation in a shallow aquifer. Less effective in low conductivity or heterogeneous aquifers.
		Phytoremediation	Use plants to remove, transfer, stabilize, or destroy contaminant in soil, sediment, and groundwater. The mechanisms of phytoremediation include rhizosphere biodegradation, phytoextraction, phytodegradation, and phytostabilization.	NOT APPLICABLE. Not implementable because this process is limited to the depth of the root zone, and the site contamination is too deep.
Disposal / Discharge	Surface	Surface Water	Discharge treated water to storm sewer system or other surface water discharge under NPDES permit.	APPLICABLE, a part of the remedy at the site. Treated groundwater was discharged to an on-site storm sewer under NPDES until 2002.
	Sewer	Public Owned Treatment Works (POTW)	Discharge treated water to public owned treatment works.	POTENTIALLY APPLICABLE. Considered in the Feasibility Study, but was not selected because treated groundwater was already reused or discharged to a storm drain (in compliance with an NPDES permit).
	Reuse	Reclamation	Provide treated groundwater as an alternate water resource to local communities or for on-site uses.	APPLICABLE, as a part of remedy in the current ROD. However, it is unlikely that this option can be an effective discharge option due to the current site use.



TABLE 11a

INITIAL SCREENING OF REMEDIAL TECHNOLOGIES

Former 901/902 Thompson Place  
Sunnyvale, California

General Response Actions	Remedial Technology	Process Option	Description	Screening Comments
Disposal / Discharge (cont'd)	Subsurface	Injection Wells	Pump treated groundwater back into subsurface.	APPLICABLE. Treated groundwater may be reinjected with substrates to enhance flushing and degradation of COCs. Injection was used at the site during the period of the active in situ bioremediation between 2005 and 2008.
		Infiltration	Discharge treated groundwater into infiltration basins/ trenches .	NOT APPLICABLE due to current site use. In addition, surficial soil at the site is not permeable.

Notes

Light yellow shaded boxes indicate process options that are retained for the secondary screening evaluation and not specified in the ROD issued in 1991.



Light green shaded boxes indicate process options that are retained for the secondary screening evaluation and were already included in the ROD issued in 1991.



Unshaded process options have been eliminated and will not be considered further.

Abbreviations

- COCs = constituents of concern
- NAPL = non-aqueous-phase liquid
- NPDES = National Pollutant Discharge Elimination System
- RAOs = Remedial Action Objectives
- ROD = Record of Decision
- VOCs = volatile organic compounds

TABLE 11b

INITIAL SCREENING OF SUPPLEMENTAL SUBSTRATE DELIVERY  
AND GROUNDWATER RECOVERY PROCESS OPTIONS

Former 901/902 Thompson Place  
Sunnyvale, California

General Response Actions	Remedial Technology	Process Option	Description	Screening Comments
Active Containment / In Situ Treatment	Supplemental Physical Process	Pneumatic Fracturing	Inject pressurized gas to produce fractures in low-permeability layers in order to increase effectiveness of in situ treatment or to facilitate groundwater extraction and delivery of chemicals/substrates in the subsurface.	POTENTIALLY APPLICABLE.
		Hydraulic Fracturing	Inject high-pressure water or a polymer gel to produce fractures in low-permeability layers in order to increase effectiveness of in situ treatment or to facilitate groundwater extraction and delivery of chemicals/substrates in the subsurface.	POTENTIALLY APPLICABLE.
		Funnel and Gate	Direct groundwater flow with low-permeability walls (funnel) to a high hydraulic conductivity treatment zone (gate). To ensure that flow beneath the system does not occur, the system must be keyed into an underlying low-permeability layer.	POTENTIALLY APPLICABLE. This depends on site use. If site use changes and access is available for heavy equipment, this could be implementable. Currently difficult to implement at the site due to space constraints.
		Directional Well	Use drilling techniques to position wells horizontally or at an angle, to reach contaminants not accessible by direct vertical drilling.	APPLICABLE. This option was successfully used to target the VOC source zone during the in situ bioremediation study.

Notes

Light yellow shaded boxes indicate process options that are retained for the secondary screening evaluation and not specified in the ROD issued in 1991.

Unshaded process options have been eliminated and will not be considered further.

Abbreviations

ROD = Record of Decision

VOC = volatile organic compound

**TABLE 12a**  
**SECONDARY SCREENING OF REMEDIAL TECHNOLOGIES**  
Former 901/902 Thompson Place  
Sunnyvale, California

General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	Screening Comments
No Further Action	No Further Action	No Action	Does not meet RAOs			<b>RETAINED.</b> Does not meet RAOs; required for comparison by the National Contingency Plan.
Monitoring	Groundwater Sampling and Monitoring	Groundwater Sampling and Monitoring	This option alone does not meet RAOs.	Readily Implementable.	Low capital, low O&M	<b>RETAINED.</b> Used as a component for remediation performance evaluation.
Institutional Controls	Groundwater Use Restrictions	Access Restrictions to Groundwater	Demonstrated.	Readily Implementable.	Low capital, low O&M	<b>RETAINED.</b> A restrictive covenant has been placed to prohibiting the use of shallow groundwater for drinking water.
Monitored Natural Attenuation (MNA)	Monitored Natural Attenuation	Monitored Natural Attenuation of Groundwater	Demonstrated, particularly for VOCs.	Readily Implementable.	Low capital, low O&M	<b>RETAINED</b> as a component of the overall groundwater remedy. May be applicable for COCs that have relatively low concentrations but higher than RAOs.
Active Containment	Contaminated Groundwater Extraction / Hydraulic Control	Groundwater Extraction	Well demonstrated and widely used. Less effective in removing contaminant mass stored in the low-permeability zones.	Readily implementable.	Low capital, moderate to high O&M	<b>RETAINED</b> in conjunction with other technologies. This is a proven technology, and has been used for containment. This option may result in net loss of groundwater for drinking water supply. Aboveground treatment system is required.
Groundwater Treatment: Aboveground	Physical Process	Air Stripping	Well demonstrated and widely used for treatment of volatile compounds.	Readily Implementable.	Low capital, moderate O&M	<b>RETAINED.</b> This process is feasible and was selected in the 1991 ROD. It currently serves as a backup treatment system at the site.
		Steam Stripping	Demonstrated but not widely used in groundwater treatment applications.	Implementable.	High capital, high O&M	<b>REJECTED.</b> This technology is not cost competitive with other comparable technologies and offers no distinctive advantages.
		Liquid-Liquid Extraction	Demonstrated but not widely used in groundwater treatment applications.	Implementable.	High capital, high O&M	<b>REJECTED.</b> This technology is not cost competitive with other comparable technologies, and offers no distinctive advantages.

**TABLE 12a**  
**SECONDARY SCREENING OF REMEDIAL TECHNOLOGIES**  
Former 901/902 Thompson Place  
Sunnyvale, California

General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	Screening Comments
<b>Groundwater Treatment: Aboveground (continued)</b>	<b>Physical-Chemical Process</b>	<b>Carbon Adsorption</b>	Well demonstrated and widely used.	Readily Implementable.	Low to moderate capital, moderate O&M	<b>RETAINED.</b> Air-phase carbon adsorption was selected to remove VOCs from the air stripping process in the 1991 ROD. The liquid-phase carbon adsorption is used to directly remove VOCs from groundwater at the site.
		Oxidation	Demonstrated.	Implementable.	High capital, high O&M	<b>REJECTED.</b> This technology is not cost competitive with other comparable technologies, and offers no distinctive advantages.
		Reverse Osmosis	Demonstrated.	Implementable.	High capital, high O&M	<b>REJECTED.</b> This technology is not cost competitive with other comparable technologies and offers no distinctive advantages.
	<b>Biological Process</b>	<b>Aerobic Bioreactors</b>	Demonstrated for removal of chlorinated ethenes at the field scale.	Implementable, AMEC has implemented this for vinyl chloride treatment in an aerated GAC vessel.	Moderate to high capital, low to moderate O&M	<b>RETAINED.</b> When it is used as a stand-alone process option, reliability is not as well demonstrated as physical-chemical processes. However, it can be part of a carbon adsorption unit, in which naturally occurring biological processes help VOC degradation.
		<b>Anaerobic Bioreactors</b>	Demonstrated. This process is feasible for VOCs. However, the reliability of a field-scale system is yet to be confirmed, and thus the overall cost is expected to be higher than other proven technologies.	Implementable, but sometimes require skilled system operators.	Moderate to high capital, low to high O&M	<b>RETAINED.</b> When it is used as a stand-alone process option, reliability not as well demonstrated as physical-chemical processes. However, it can be part of a carbon adsorption unit, in which naturally occurring biological processes help VOC degradation.

**TABLE 12a**  
**SECONDARY SCREENING OF REMEDIAL TECHNOLOGIES**  
Former 901/902 Thompson Place  
Sunnyvale, California

General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	Screening Comments
<b>In Situ Treatment</b>	<b>In Situ Physical Treatment</b>	Thermal Treatment	Demonstrated. This process is effective for VOC source zone remediation; however, it may be difficult to reduce VOC concentrations in groundwater below MCLs.	Implementable.	High capital, high O&M	REJECTED because of its relatively high cost and its potential ineffectiveness to address dilute VOC concentrations in highly heterogeneous aquifers.
		Air Sparging	Demonstrated for VOC contamination in groundwater. Less effective in heterogeneous aquifers.	Implementable.	High capital, low to moderate O&M	REJECTED because of the heterogeneous nature of site hydrogeology.
		Water Flushing	Demonstrated in the homogeneous subsurface. Heterogeneity may greatly limit the extent of flushing.	Implementable.	Moderate capital, low to moderate O&M	REJECTED. The remaining VOC sources are probably stored in low hydraulic conductivity zones and cannot be easily extracted through water flushing.
		Cosolvent / Surfactant Flushing	Demonstrated for VOC NAPL source zone removal. Contaminants not destroyed in situ. Aboveground treatment required.	Implementable.	High capital, moderate O&M	REJECTED due to its relatively high cost. This process option is primarily used to deal with DNAPL sources; however, there are no DNAPL sources at the site.
	<b>In Situ Chemical Treatment</b>	<b>In Situ Chemical Reduction</b>	Zero valent iron (ZVI) has been used to degrade TCE, cDCE, and VC in groundwater, and it is capable of providing long-term VOC treatment.	Implementable, but may require other geotechnical technologies to enhance substrate delivery.	Moderate capital, low O&M	<b>RETAINED.</b> A ZVI barrier at the site boundary or hotspots may be potentially economical for controlling VOC mass discharge if the PRB life span is longer than the source longevity. The reduction option is compatible with the reducing conditions created through ISB at the site.
		In Situ Chemical Oxidation	Demonstrated for VOC source zone removal. Contaminants destroyed in situ; however, injected oxidants may be naturally attenuated in a short period of time. Typically used for hotspot treatment in an oxygenic aquifer with low organic carbon content.	Implementable. Most failures attributed to channeling in heterogeneous media.	Moderate capital, moderate O&M	REJECTED. The key hot spots have been addressed through ISB. Chemical delivery may be poor in all but high permeability media. The oxidation option is not compatible with the ISB approach currently used at the site.

**TABLE 12a**  
**SECONDARY SCREENING OF REMEDIAL TECHNOLOGIES**  
Former 901/902 Thompson Place  
Sunnyvale, California

General Response Actions	Remedial Technology	Process Options	Effectiveness	Implementability	Cost	Screening Comments
<b>In Situ Treatment (continued)</b>	<b>In Situ Biological Treatment</b>	<b>Enhanced Anaerobic Microbial Degradation - Direct Substrate Addition</b>	Demonstrated and widely used for treating chlorinated ethenes. Contaminants destroyed in situ. Various substrate types and delivery approaches available. Geologic heterogeneity may significantly affect the extent of substrate delivery.	Implementable, but may require other geotechnical technologies to enhance substrate delivery. Pilot testing needed to evaluate implementability at the site.	Low to moderate capital, low to moderate O&M	<b>RETAINED.</b> The site is suitable for in situ bioremediation as demonstrated through the full-scale ISB program. Direct injection of substrates in target area may help further reduce VOC discharge.
		<b>Enhanced Anaerobic Microbial Degradation - Groundwater Recirculation System</b>	Demonstrated and widely used for chlorinated ethenes. Contaminants destroyed in situ. Various substrate types and delivery approaches available. Geologic heterogeneity may significantly affect the extent of substrate delivery.	Implementable, but aquifer hydraulic conductivity must be high enough for circulating flow to be established. Pilot testing needed to evaluate implementability at the site.	Low to moderate capital, low to moderate O&M	<b>RETAINED.</b> The effectiveness of this option has been demonstrated through the full-scale ISB program.
<b>Disposal / Discharge</b>	<b>Surface</b>	<b>Surface Water</b>	Demonstrated.	Implementable.	Moderate capital, low to moderate O&M	<b>RETAINED.</b> It has been the main discharge option for the site.
	<b>Sewer</b>	Public Owned Treatment Works (POTW)	Demonstrated.	Implementable.	Low capital, high O&M	<b>REJECTED.</b> Required for evaluation by the Water Board. This option is potentially much more costly over time compared to other discharge options.
	<b>Reuse</b>	<b>Reclamation</b>	Demonstrated.	Implementable.	Low capital, low O&M	<b>RETAINED.</b> The option is part of the 1991 ROD. Treated water may be used for non-drinking-water purposes.
	<b>Subsurface</b>	<b>Injection Wells</b>	Demonstrated.	Implementable.	Moderate capital, high O&M	<b>RETAINED.</b> Injection of treated groundwater together with organic substrates into the aquifer. This option was used at the site during the period of active ISB between 2005 and 2008.

**TABLE 12a**  
**SECONDARY SCREENING OF REMEDIAL TECHNOLOGIES**  
Former 901/902 Thompson Place  
Sunnyvale, California

Notes

Shaded boxes indicate process options that are retained for the secondary screening evaluation.  
Unshaded process options have been eliminated and will not be considered further.

Abbreviations

- |  |                                   |
|--|-----------------------------------|
| cDCE = cis-1,2-dichloroethene          | NAPL = non-aqueous-phase liquid   |
| TCE = trichloroethene                  | O&M = operations and maintenance  |
| VC = vinyl chloride                    | PRB = permeable reactive barrier  |
| COCs = constituents of concern         | RAOs = Remedial Action Objectives |
| MCL = maximum contaminant level        | ROD = Record of Decision          |
| DNAPL = dense non-aqueous-phase liquid | VOCs = volatile organic compounds |
| ISB = in situ bioremediation           | ZVI = zero valent iron            |

TABLE 12b  
SECONDARY SCREENING OF SUPPLEMENTAL SUBSTRATE DELIVERY  
AND GROUNDWATER RECOVERY PROCESS OPTIONS  
Former 901/902 Thompson Place  
Sunnyvale, California

General Response Actions	Remedial Technology	Process Option	Effectiveness	Implementability	Cost	Screening Comments
Active Containment / In Situ Treatment	Supplemental Physical Process	Pneumatic Fracturing	Demonstrated. Has been found to facilitate substrates and ZVI delivery in tight formations or low hydraulic conductivity zones.	Implementable.	Moderate capital, moderate O&M	RETAINED. Potentially applicable in conjunction with other technologies to increase pumping yield or the effectiveness of substrate delivery.
		Hydraulic Fracturing	Demonstrated.	Implementable.	Moderate to high capital, low O&M	REJECTED because it creates a lower density of fracture network and probably a smaller zone of influence in comparison with pneumatic fracturing.
		Directional Well	Demonstrated. This type of well is usually within 100 feet of ground surface.	Implementable.	Moderate capital, high O&M	RETAINED. Potentially applicable in conjunction with other in situ technologies to increase their effectiveness.

Notes

Shaded boxes indicate process options that are retained for the secondary screening evaluation.  
Unshaded process options have been eliminated and will not be considered further.

Abbreviations

O&M = operations and maintenance  
ZVI = zero valent iron



**TABLE 13**  
**MAJOR COMPONENTS OF REMEDIAL ALTERNATIVES**  
 Former 901/902 Thompson Place  
 Sunnyvale, California

Remedial Alternative	GW Extraction	ISB	PRB	Ex Situ GW Treatment	MNA	Use of Treated GW	GW Monitoring
1. No Further Action	--	--	--	--	--	--	--
2. GWET	X	--	--	X	--	discharge to storm drains or reuse	X
3. MNA + GWET	X	--	--	X	X	discharge to storm drains or reuse	X
4. ISB + MNA	--	X	--	X	X	reinjection	X
5. PRB	--	--	X	--	--	--	X

Abbreviations

GW = groundwater

GWET = groundwater extraction and treatment

ISB = in situ bioremediation

MNA = monitored natural attenuation

PRB = permeable reactive barrier

**TABLE 14**  
**COST ESTIMATES FOR REMEDIAL ALTERNATIVES <sup>1</sup>**  
Former 901/902 Thompson Place  
Sunnyvale, California

Remedial Alternative	Capital Cost <sup>2</sup>	Annual O&M Cos t <sup>2</sup>	Total Cost
<b>1. No Further Action</b>	NA	\$0	\$0
<b>2. GWET</b>	NA	\$115,000	\$1,530,000
<b>3. MNA + GWET</b>	NA	\$102,000	\$1,359,000
<b>4. ISB + MNA <sup>3</sup></b>	NA	\$151,000	\$947,000
<b>5. PRB</b>	\$1,168,000	\$60,000	\$1,965,000

Notes

1. See Appendix E for more detail.
2. Costs rounded to the nearest thousands.
3. Annual O&M cost for ISB + MNA in this table is based on the highest annual cost during the operation period.

Abbreviations

GW = groundwater	NA = not available
GWET = groundwater extraction and treatment	O&M = operations and maintenance
ISB = in situ bioremediation	PRB = permeable reactive barrier
MNA = monitored natural attenuation	

TABLE 15  
COMPARISON OF REMEDIAL ALTERNATIVES  
Former 901/902 Thompson Place  
Sunnyvale, California

Feasibility Evaluation Criteria												
	Overall Protection of Human Health and Environment			Compliance with ARARs			Long-Term Effectiveness and Permanence	Reduction in Toxicity, Mobility, and Volume	Short-Term Effectiveness	Implementability		Cost
Remedial Alternative	Prevents Migration to Downgradient Area	Protection Against the Use of GW	Reduces Exposure of Potential Vapor Intrusion	Cleanup Standards for Groundwater	Discharge and Injection Limits	Time to Reach Upgradient GW Conditions	Optimizes Removal or Reduction of COCs to Reduce Long-Term Reliance on O&M	COC Distribution and Concentration	Protection During Construction and Implementation Period	Remedial Facilities in Place	Engineering Services, Materials, Approvals, and Permits	Estimated Total Costs
RA-1: No Further Action	No, impacted GW moves downgradient.	Institutional controls will be implemented at the site to prevent the use of GW before it reaches the cleanup standards.	Natural attenuation processes are responsible for the concentration decrease in shallow GW.	For all RAs, the ability to meet the GW cleanup standards depends on the off-site upgradient GW quality.	NA	RA-1 does not accelerate the time to reach the upgradient GW conditions.	RA-1 does not actively reduce or remove COCs from impacted GW.	RA-1 cannot effectively reduce the extent of COCs and concentrations in site GW.	The risk associated with site-related COCs has been greatly reduced through various remedial actions for the past three decades. The additional risk associated with construction and implementation of any of the RAs is expected to be minimal and manageable.	NA	Engineering service, materials, and regulatory approvals and permits for construction of a new installation or expansion of the existing extraction and ISB systems are expected to be readily obtainable.	\$0
RA-2: GWET	Yes, hydraulic control will prevent COCs from moving off site.		Enhanced flushing through GW extraction will help reduce concentrations in shallow GW to some extent.		Discharge of treated water will comply with requirements specified in the NPDES permit.	GW extraction enhances the desorption of COCs from the low-permeability zones, thereby reducing the time to reach the upgradient GW conditions.	RA-2 and RA-3 moderately reduce the time to remediate the site. They are not as effective as RA-4 because they do not promote COC destruction in the low-permeability zones.	GW extraction can reduce the extent and concentrations of COCs in site GW, but its effectiveness is limited by the desorption of COCs from the low-permeability zones.		Yes		\$1,530,000
RA-3: MNA for A Zone GWET for B Zones	Yes, hydraulic control will prevent COCs from moving off site in the B zones. Small mass flux of COCs leaving from the A zone is expected due to intrinsic microbial activity and pumping in the B zones.		Similiar to RA-1.							Yes		\$1,359,000
RA-4: ISB and MNA	Yes, GW recirculation and microbial degradation will prevent COCs from moving off site. When the upgradient GW conditions prevail at the site, MNA will be used to polish groundwater quality.		RA-4 optimizes the removal of COC mass by enhancing biodegradation and flushing in shallow GW through substrate addition and GW circulation, reducing both exposure concentrations and time frame.		Injected nutrient solution will comply with the criteria established by the Water Board.	ISB can achieve upgradient GW conditions in the shortest time frame since it is the most effective RA to remove COCs from low-permeability zones.	RA-4 optimizes the removal of COC mass in the low-permeability zones and is capable of significantly reducing the time to reach upgradient GW conditions.	ISB will reduce the extent and concentration of COCs in site GW concurrently and effectively.		Yes		\$947,000
RA-5: PRB	Yes, COCs will be destroyed by the PRB.		Similiar to RA-1. Significant COC destruction only occurs within the PRB.			NA	Similar to RA-1.	Similar to RA-1.		Similar to RA-1.		No

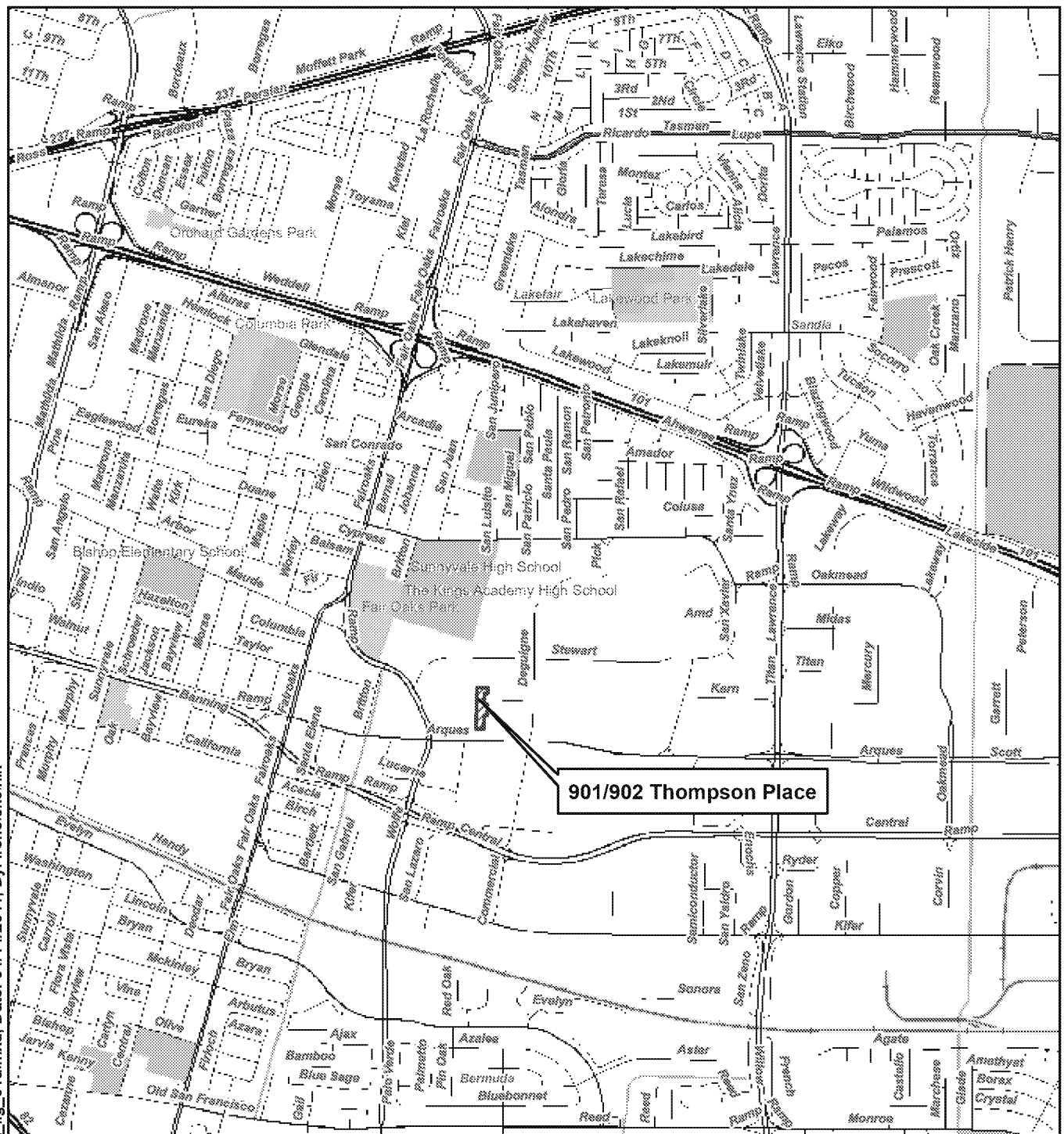
Abbreviations

ARARs = applicable or relevant and appropriate requirements; COC = constituent of concern; GW = groundwater; GWET = groundwater extraction and treatment; ISB = in situ bioremediation; MNA = monitored natural attenuation; NA = not applicable; NPDES = national pollutant discharge elimination system; O&M = operations and maintenance; RA = remedial alternative; PRB = permeable reactive barrier

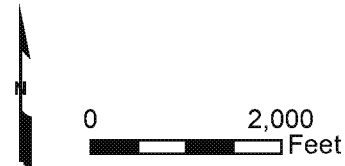
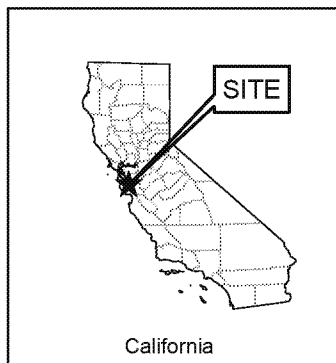
---

**FIGURES**

File path: S:\OD10\160080\task\_0003\11\_0317\_fs\fig\_01a.mxd; Date: 04/14/2011; By: irene.skolnik



Base map from StreetMapPro 2007 (Environmental Systems Research Institute, Inc. [ESRI], 2007).



**SITE LOCATION MAP**  
Former 901/902 Thompson Place  
Sunnyvale, California

By: MC	Date: 04/14/2011	Project No. OD10160080
--------	------------------	------------------------

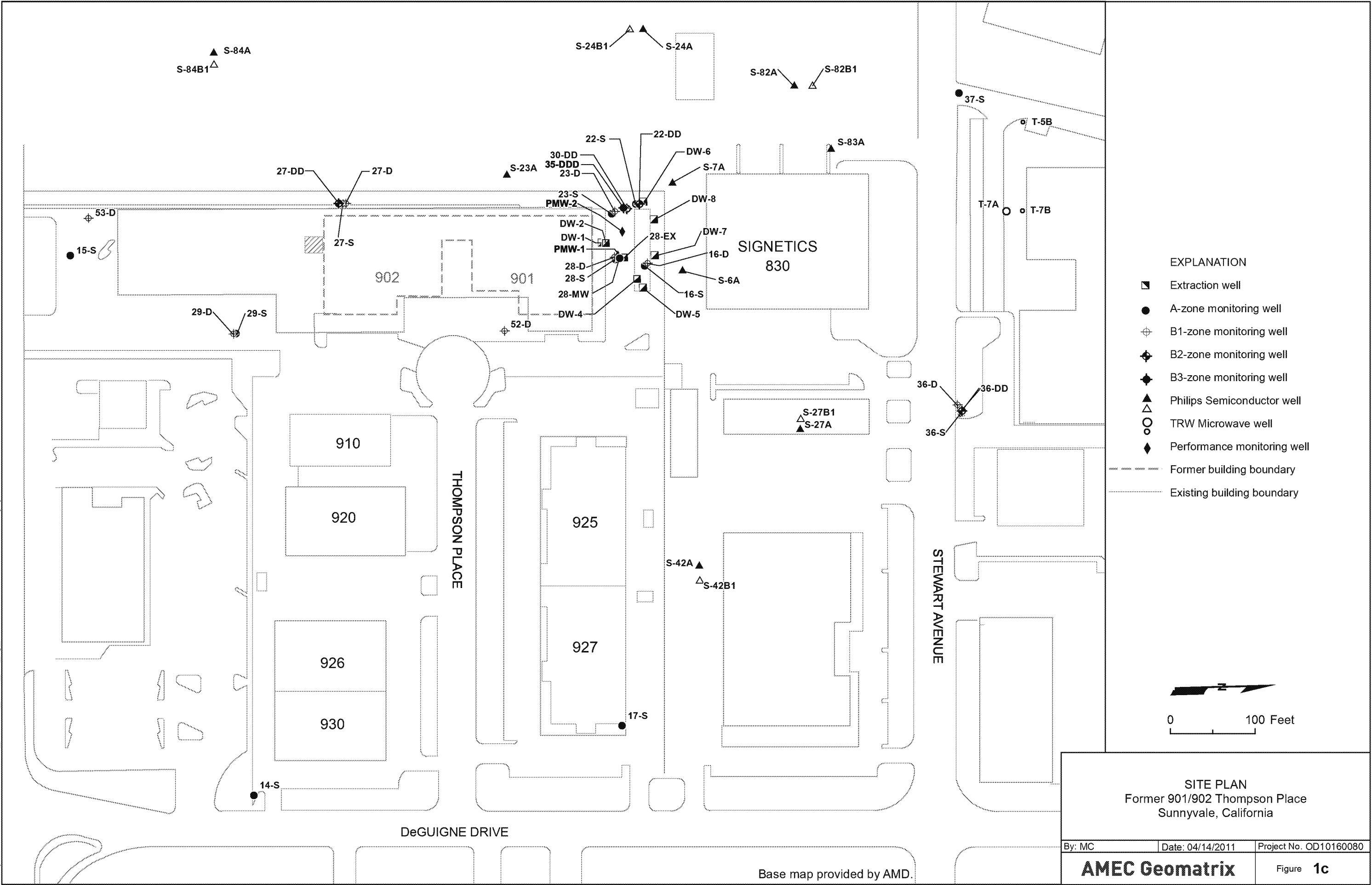
**AMEC Geomatrix**

Figure **1a**

ED\_006475C\_00003377-00097

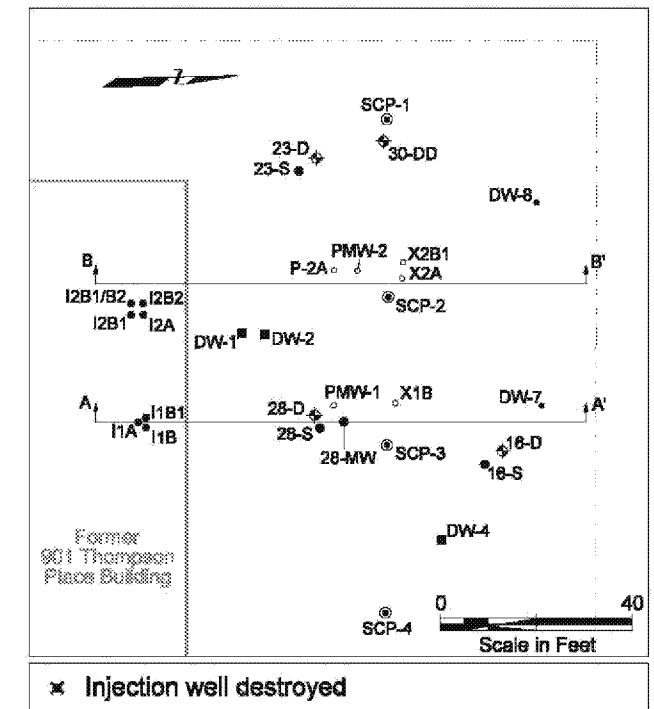
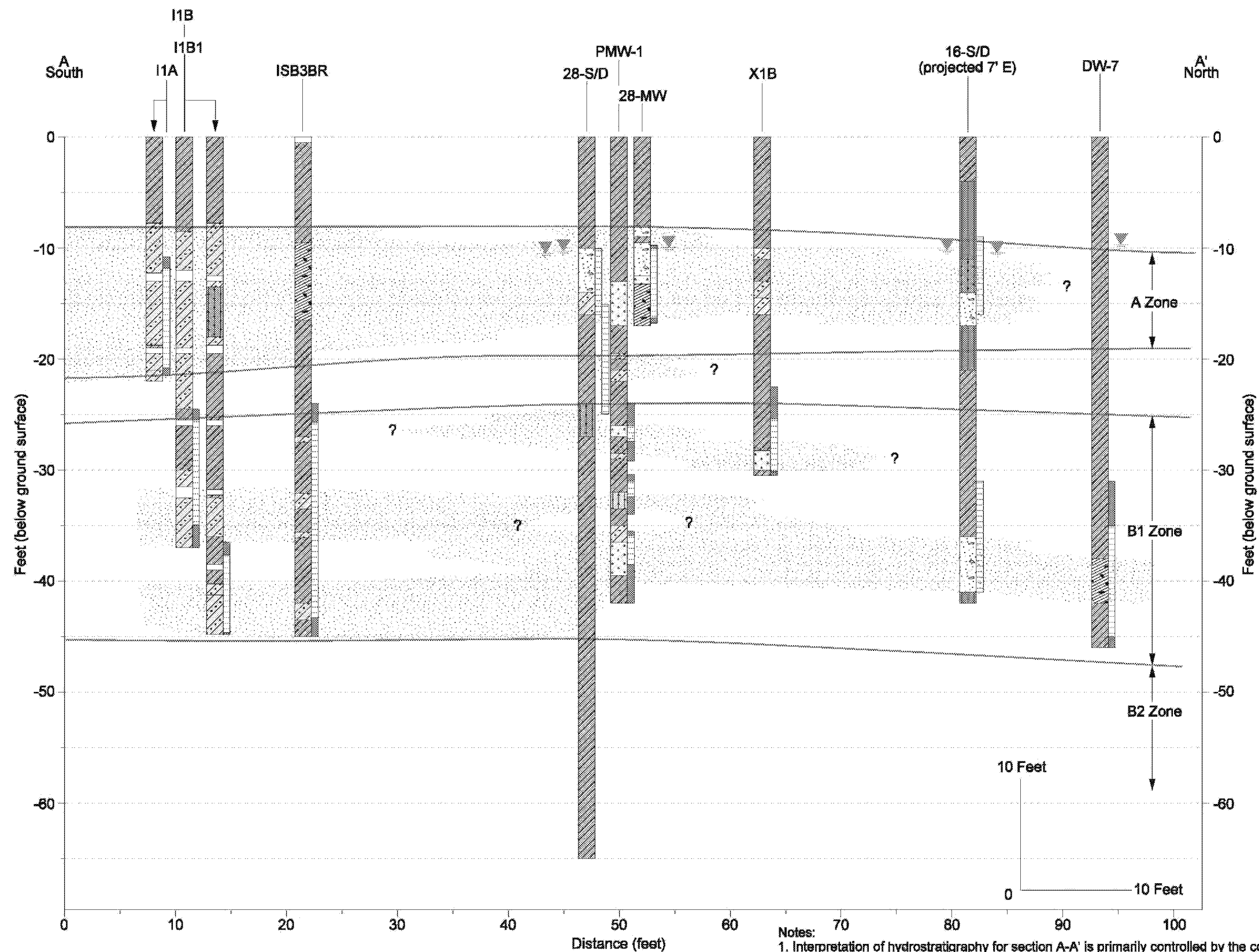


File path: S:\OD10160080\task\_000311\_0317\_ffs\fig\_01b.mxd; Date: 04/14/2011; By: jacob.chu



























**EXPLANATION**

	Gravel GP or GW		Silty sands SM
	Gravel with silt GW-GM or GP-GM		Clayey gravel GC
	Gravel with clay GW-GC or GP-GC		Clayey sand SC
	Sand SW or SP		Silt ML or MH
	Sand with silt SW-SM or SP-SM		Clay CL or CH
	Sand with clay SW-SC or SP-SC		No recovery
	Silty gravel GM		Screened interval
	Water table		Filter pack interval

HYDROSTRATIGRAPHY

 Interpreted low-permeability zone

 Interpreted moderate- to high-permeability zone

Stratigraphic contacts drawn for clarity only and do not imply certainty.

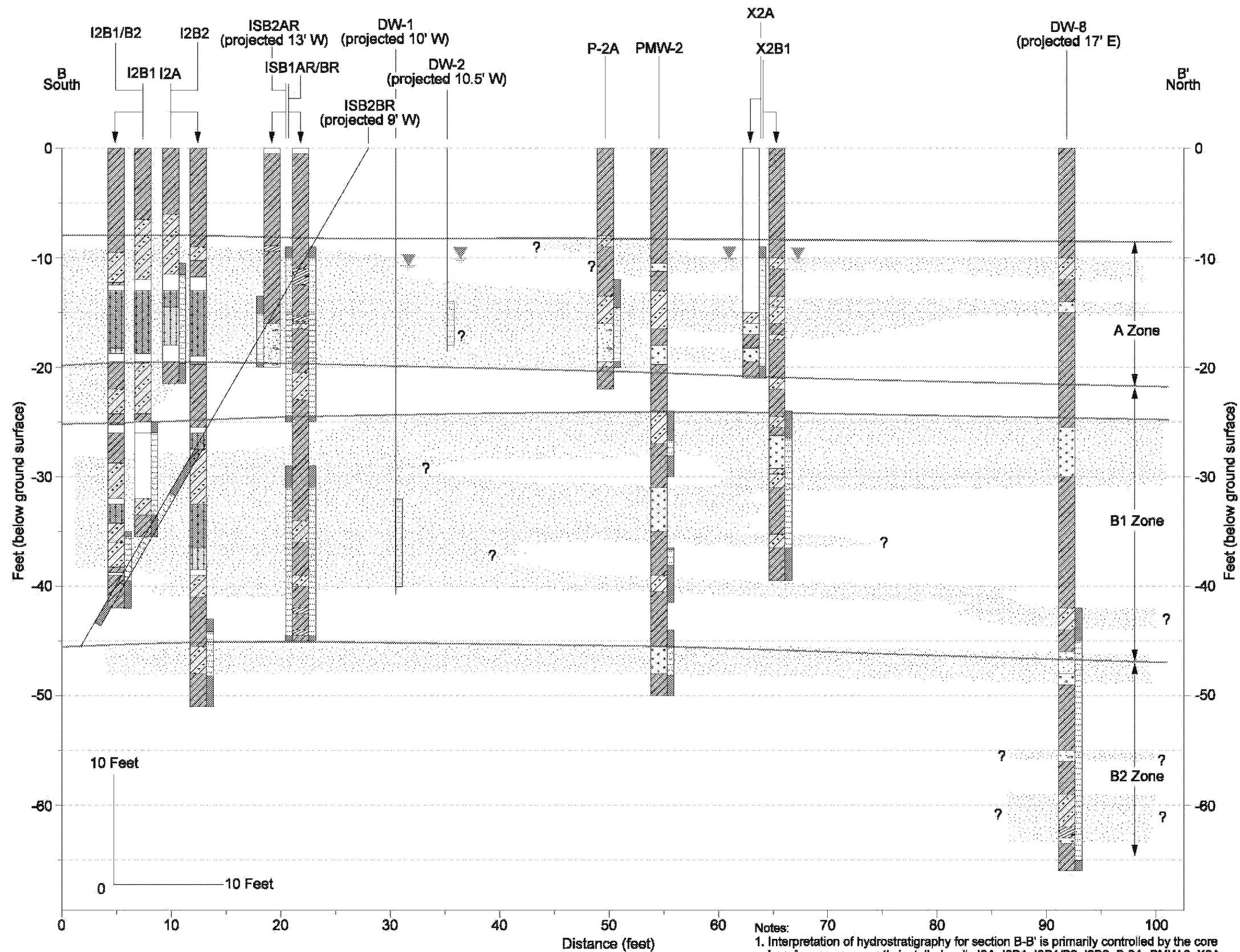
CROSS SECTION A-A'  
Former 901/902 Thompson Place  
Sunnyvale, California

By: _____	Date: 4/14/2011	Project No. OD10160080
-----------	-----------------	------------------------

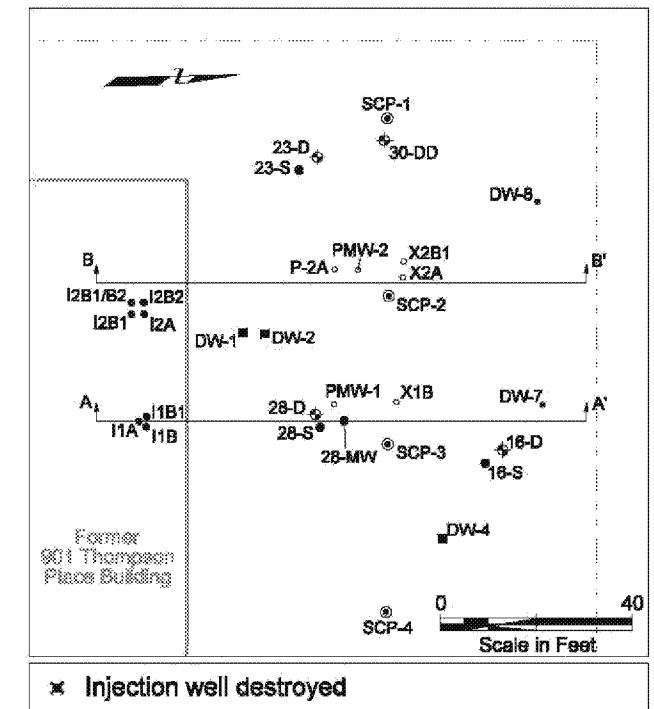
**AMEC Geomatrix**

Figure 2a

\\odc-pr2\0AD-13F\plot  
s:\010160080\Task\_0003\11\_0317\_ffs\fig\_02b.dgn  
Q:\plot\actb\geomtr\c.ctb Q:\plot\penMAP\_4mv.pen



Notes:  
1. Interpretation of hydrostratigraphy for section B-B' is primarily controlled by the core logs from more recently installed wells I2A, I2B1, I2B1/B2, I2B2, P-2A, PMW-2, X2A, and X2B1, which were logged continuously using visual-manual procedures. Hydrostratigraphy is controlled to a lesser extent by logs for previously installed wells.  
2. Injection wells I2A, I2B1, I2B1/B2, and I2B2 were destroyed in May 2006 to accommodate the property owner's construction activities.  
3. Replacement wells ISB1AR, ISB2AR, ISB1BR, and ISB2BR were installed on 2/28/07, 3/1/07, 2/28/07, and 3/6/07, respectively.



#### EXPLANATION

Gravel GP or GW	Silty sands SM
Gravel with silt GW-GM or GP-GM	Clayey gravel GC
Gravel with clay GW-GC or GP-GC	Clayey sand SC
Sand SW or SP	Silt ML or MH
Sand with silt SW-SM or SP-SM	Clay CL or CH
Sand with clay SW-SC or SP-SC	No recovery
Silty gravel GM	Screened interval
Water table	Filter pack interval

#### HYDROSTRATIGRAPHY

Interpreted moderate- to high-permeability zone

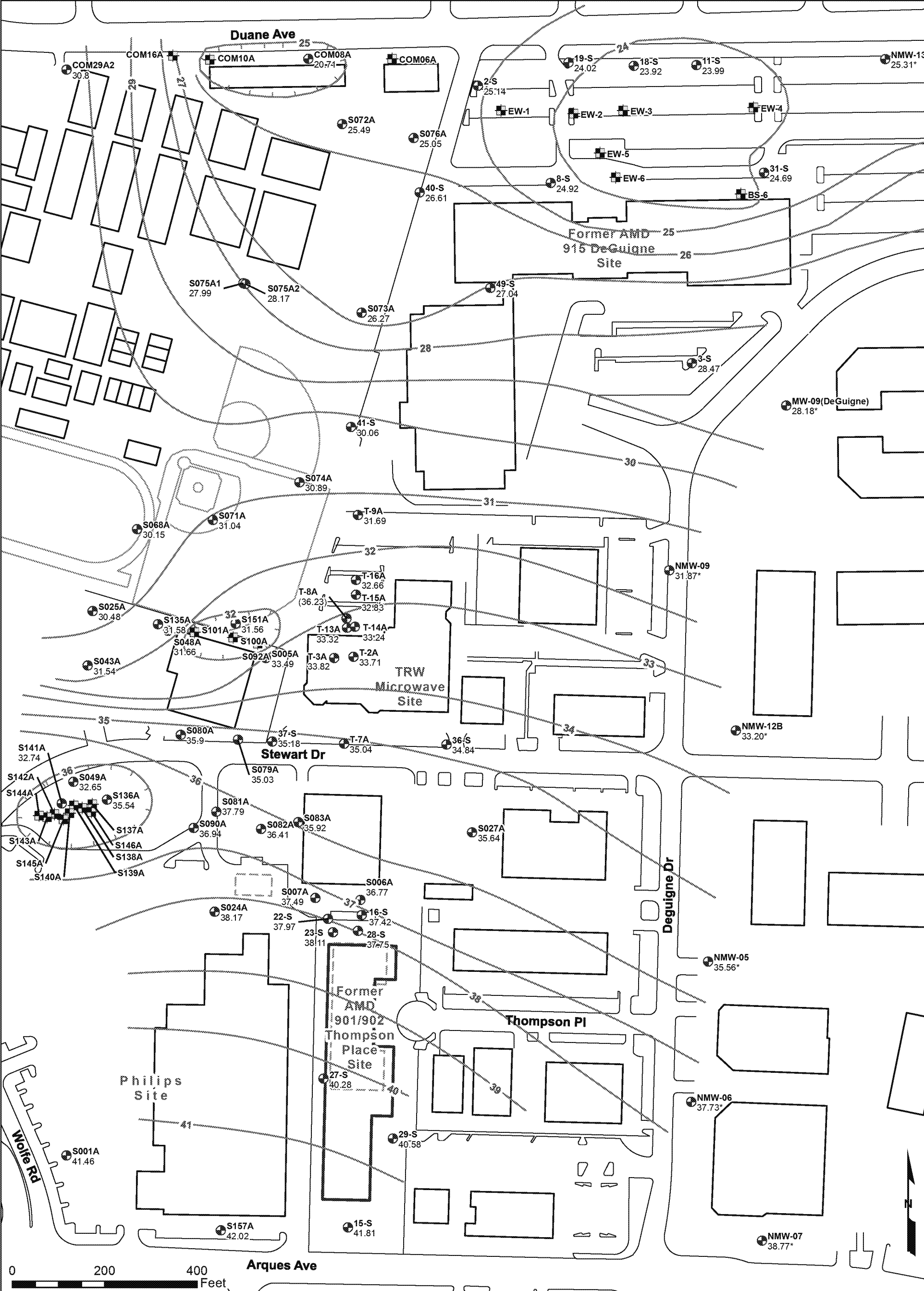
Stratigraphic contacts drawn for clarity only and do not imply certainty.




CROSS SECTION B-B'  
Former 901/902 Thompson Place  
Sunnyvale, California

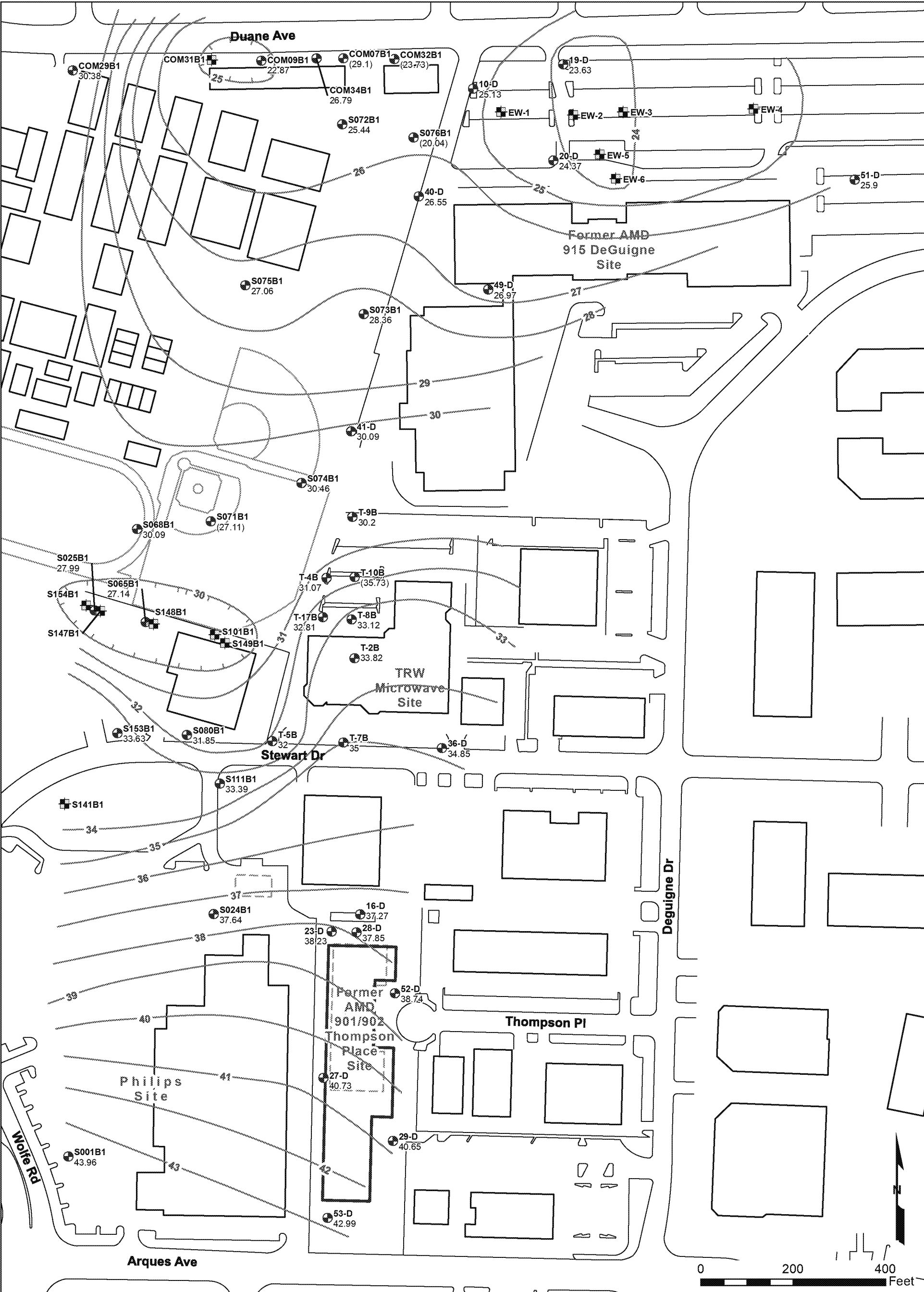
By: \_\_\_\_\_ Date: 4/14/2011 Project No. OD10160080

**AMEC Geomatrix**

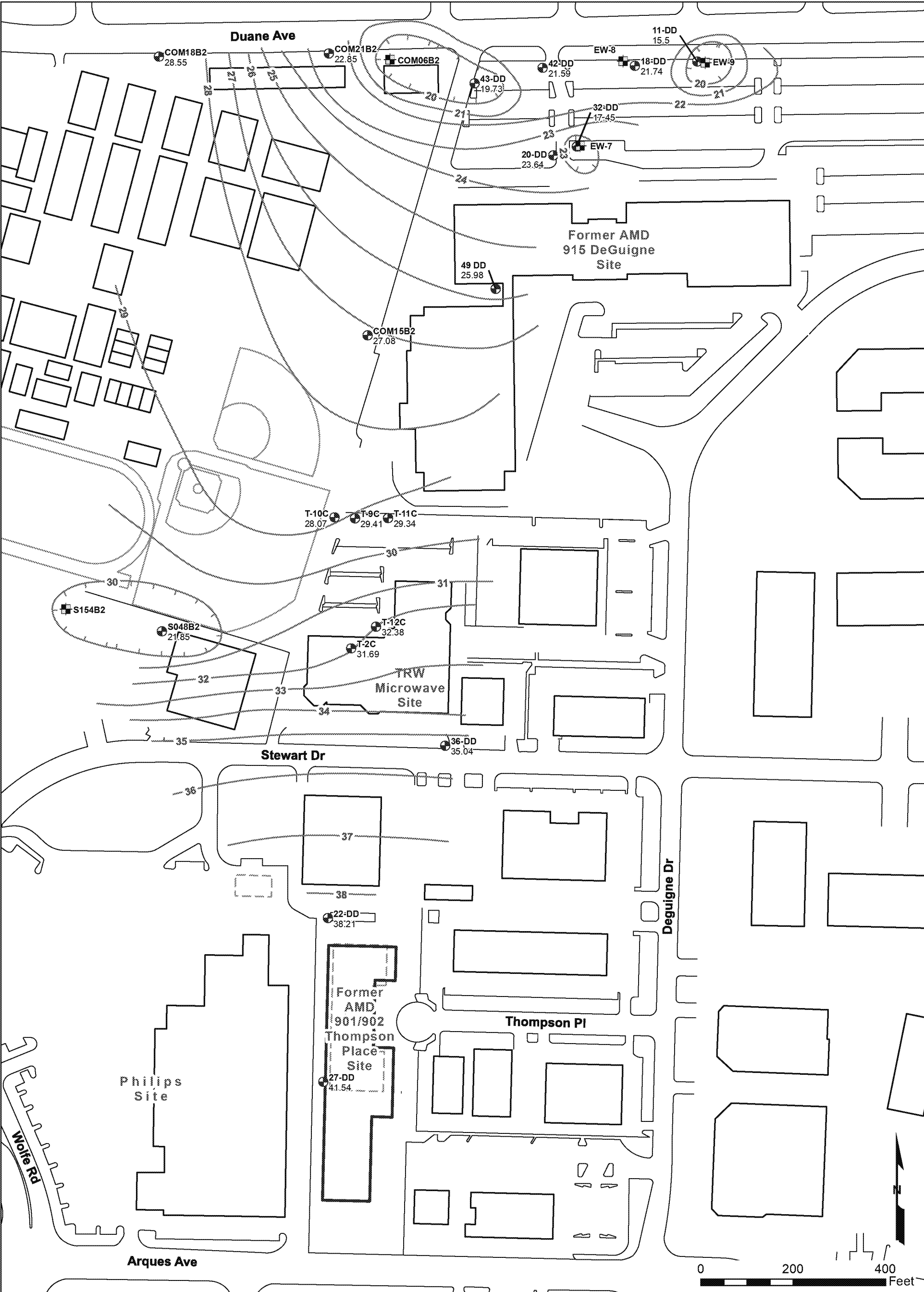
Figure **2b**



<b>EXPLANATION</b>		36.56* "NMW" group of wells and MW-09 (DeGuigne) are surveyed to a different datum (NGVD29); therefore, groundwater elevations differ by approximately 2.8 feet relative to NAVD88.	<div>A-ZONE WATER LEVELS OCTOBER 11, 2010 Former 901/902 Thompson Place Sunnyvale, California</div> <div>By: _____Date: 04/14/2011Project No. OD10160080</div> <div>AMEC Geomatrix</div> <div>Figure 3a</div>		
	Extraction well				
	Monitoring well				
	Line of equal groundwater elevation				
33.71	Groundwater elevation, feet (NAVD88)				
(36.23)	Elevation not used for contouring	Notes: 1. Contours are based on interpretation of monitoring well data and current understanding of hydrogeologic conditions. They are provided for clarity and are not intended to imply certainty. 2. EW-1 through EW-6 are screened across both the A and B1 zones.			



<p>EXPLANATION</p> <p> Extraction well</p> <p> Monitoring well</p> <p>—26— Line of equal groundwater elevation</p> <p>37.85 Groundwater elevation, feet (NAVD88)</p> <p>(35.73) Elevation not used for contouring</p>		<p>Notes:</p> <p>1. Contours are based on interpretation of monitoring well data and current understanding of hydrogeologic conditions. They are provided for clarity and are not intended to imply certainty.</p> <p>2. EW-1 through EW-6 are screened across both the A and B1 zones.</p>		<p>B1-ZONE WATER LEVELS OCTOBER 11, 2010 Former 901/902 Thompson Place Sunnyvale, California</p>	
By: _____		Date: 04/14/2011		Project No. OD10160080	
AMEC Geomatrix		Figure		3b	











<div><div>EXPLANATION</div><div><div><div><div></div></div></div><div>Extraction well</div></div><div><div><div></div></div></div><div>Monitoring well</div></div> <div><div><div><div></div></div></div><div>Line of equal groundwater elevation</div></div> <div><div><div></div></div></div> <div>Groundwater elevation, feet (NAVD88)</div>
---

The diagram illustrates a data table structure with five columns:

- Well ID**: The first column.
- Sampling date**: The second column.
- Concentration in micrograms per liter ( $\mu\text{g/L}$ )**: The third column.
- Concentration in milligrams per liter ( $\text{mg/L}$ )**: The fourth column.
- Analyte**: The fifth column.

PCE = Tetrachloroethene  
TCE = Trichloroethene  
cDCE = cis-1,2-Dichloroethene  
VC = Vinyl chloride  
TOC = Total organic carbon  
< = Analyte not detected above the laboratory  
reporting limit shown  
ND = Not detected  
NA = Not applicable

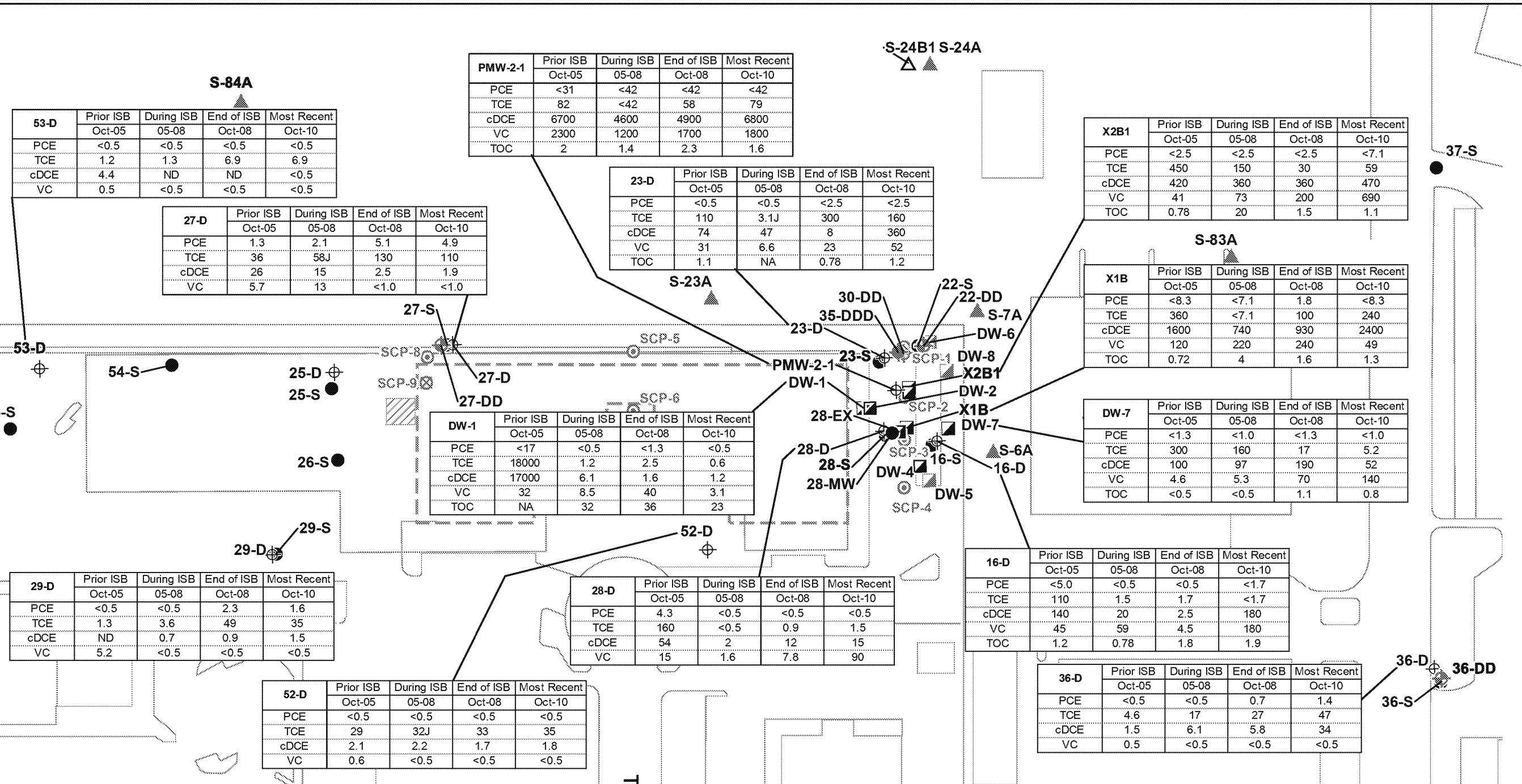
## Figure 4a

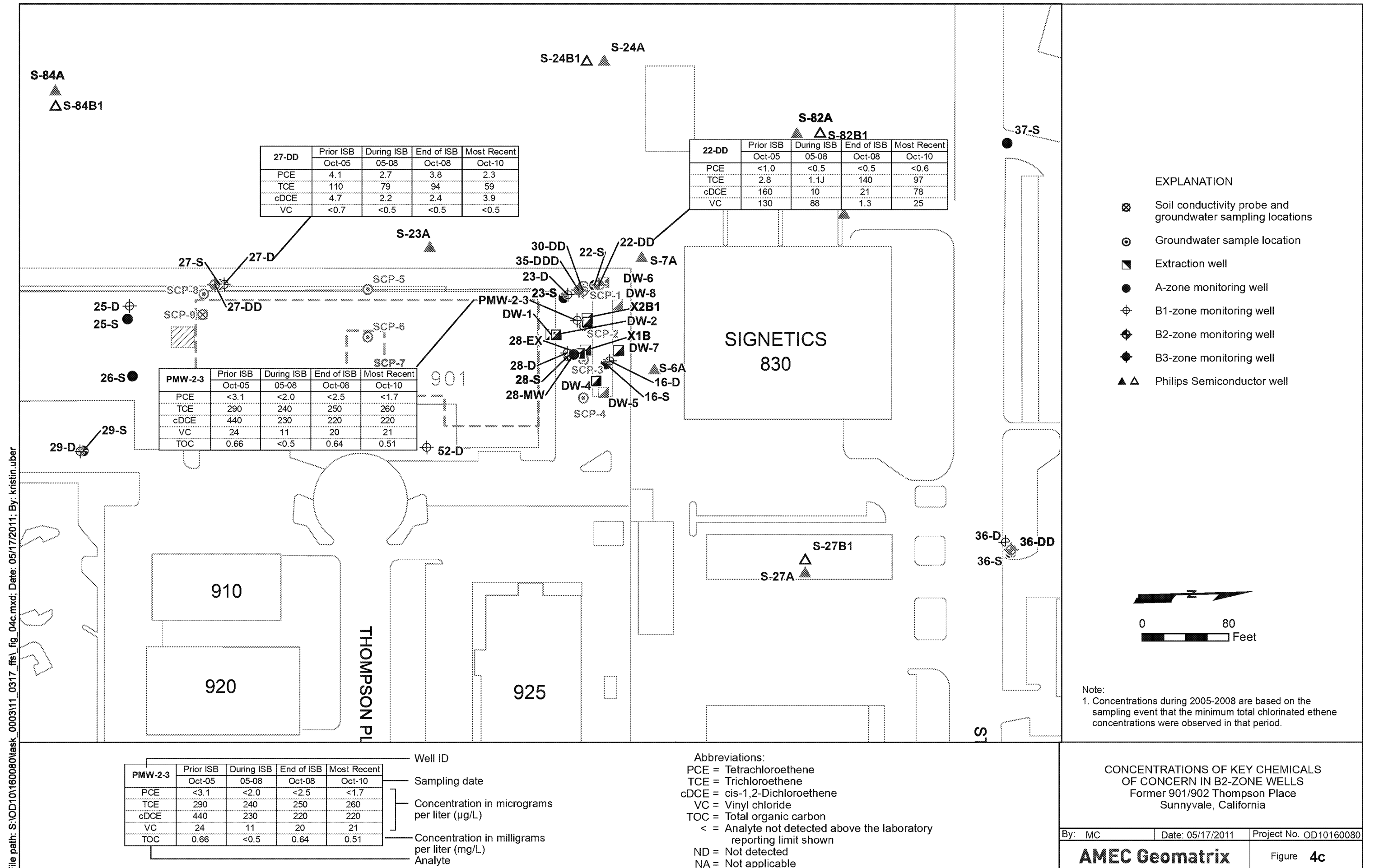
	Soil conductivity probe and groundwater sampling locations
	Groundwater sample location
	Extraction well
	A-zone monitoring well
	B1-zone monitoring well
	B2-zone monitoring well
	B3-zone monitoring well
	Philips Semiconductor well

36-S	Prior ISB	During ISB	End of ISB	Most Recent
	Oct-05	05-08	Oct-08	Oct-10
PCE	2.1	1.5	2	2
TCE	91	70	98	75
cDCE	22	15	13	11
VC	<1.0	<0.5	<0.5	<0.5

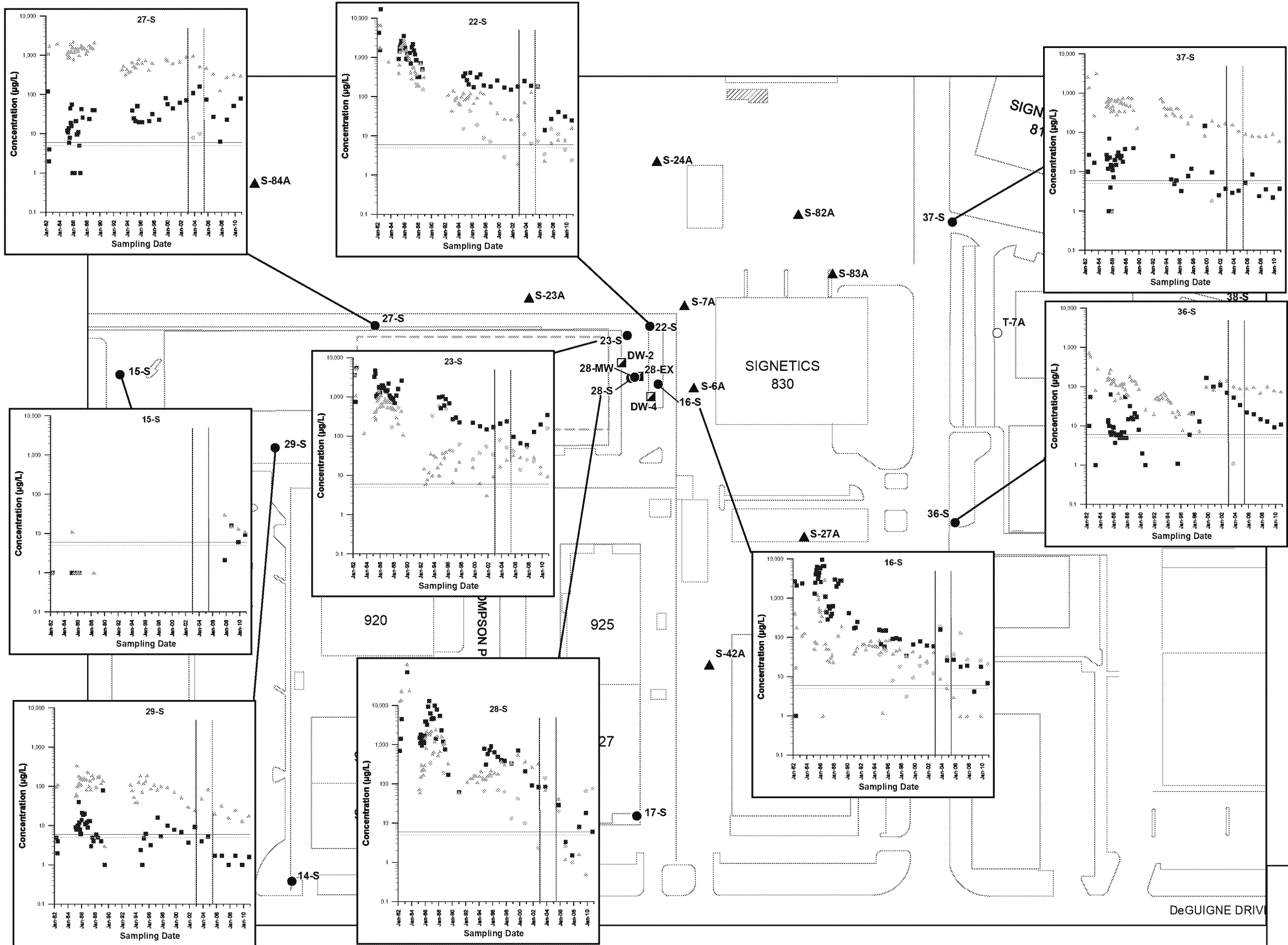


File path: S:\OD10160080\task\_0003111\_ffs\fig\_04b.mxd; Date: 05/17/2011; By: kristin.uber



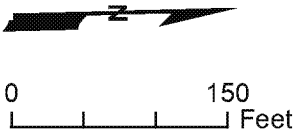






EXPLANATION

- Extraction well
- A-zone monitoring well
- TRW Microwave well
- Performance monitoring well
- Former building boundary
- Existing building boundary
- cDCE
- TCE
- VC
- Cleanup goal for TCE
- Cleanup goal for cDCE
- Start of full-scale in situ bioremediation program
- Termination of the GWET system



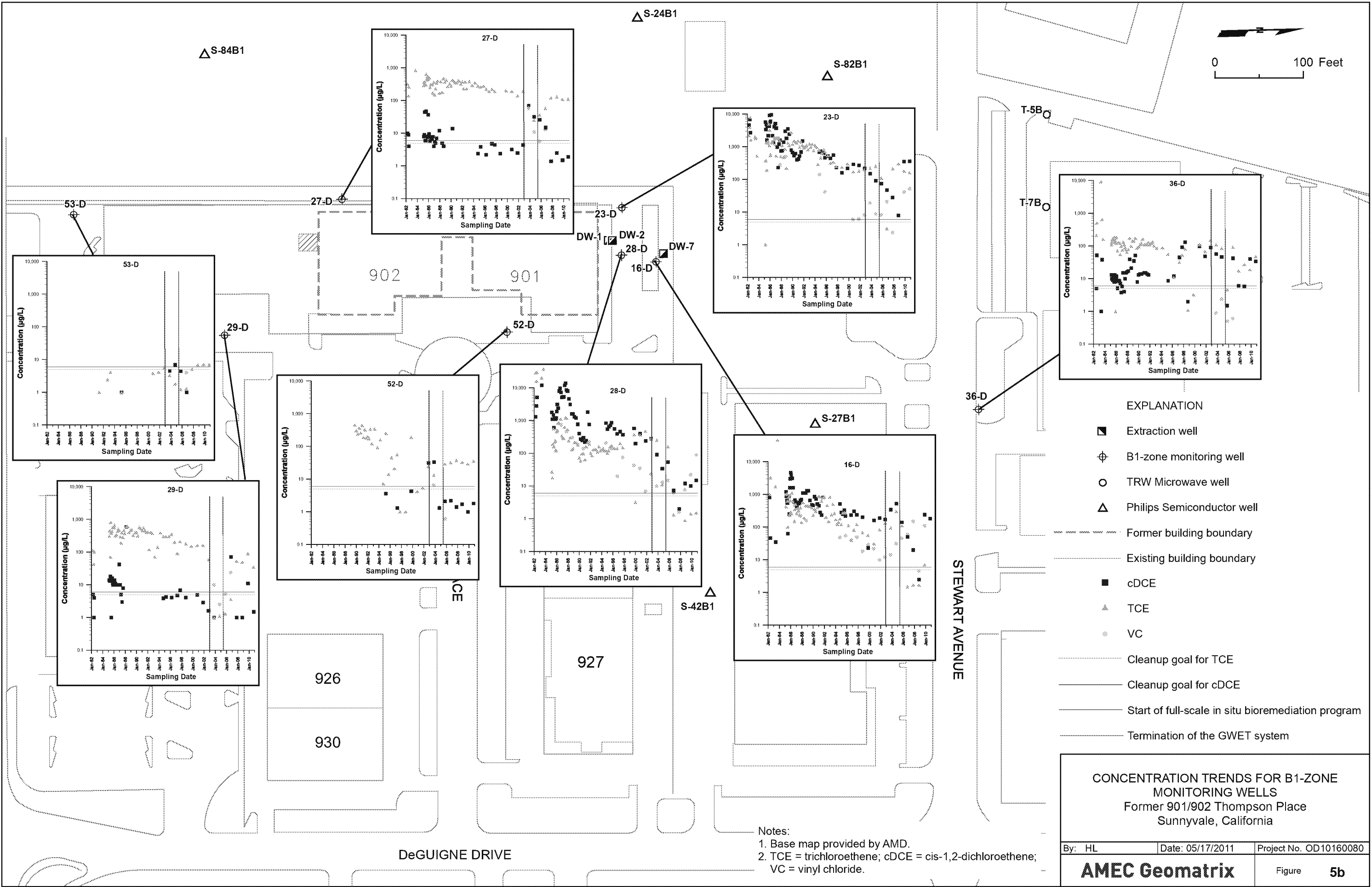
CONCENTRATION TRENDS FOR A-ZONE MONITORING WELLS  
Former 901/902 Thompson Place  
Sunnyvale, California

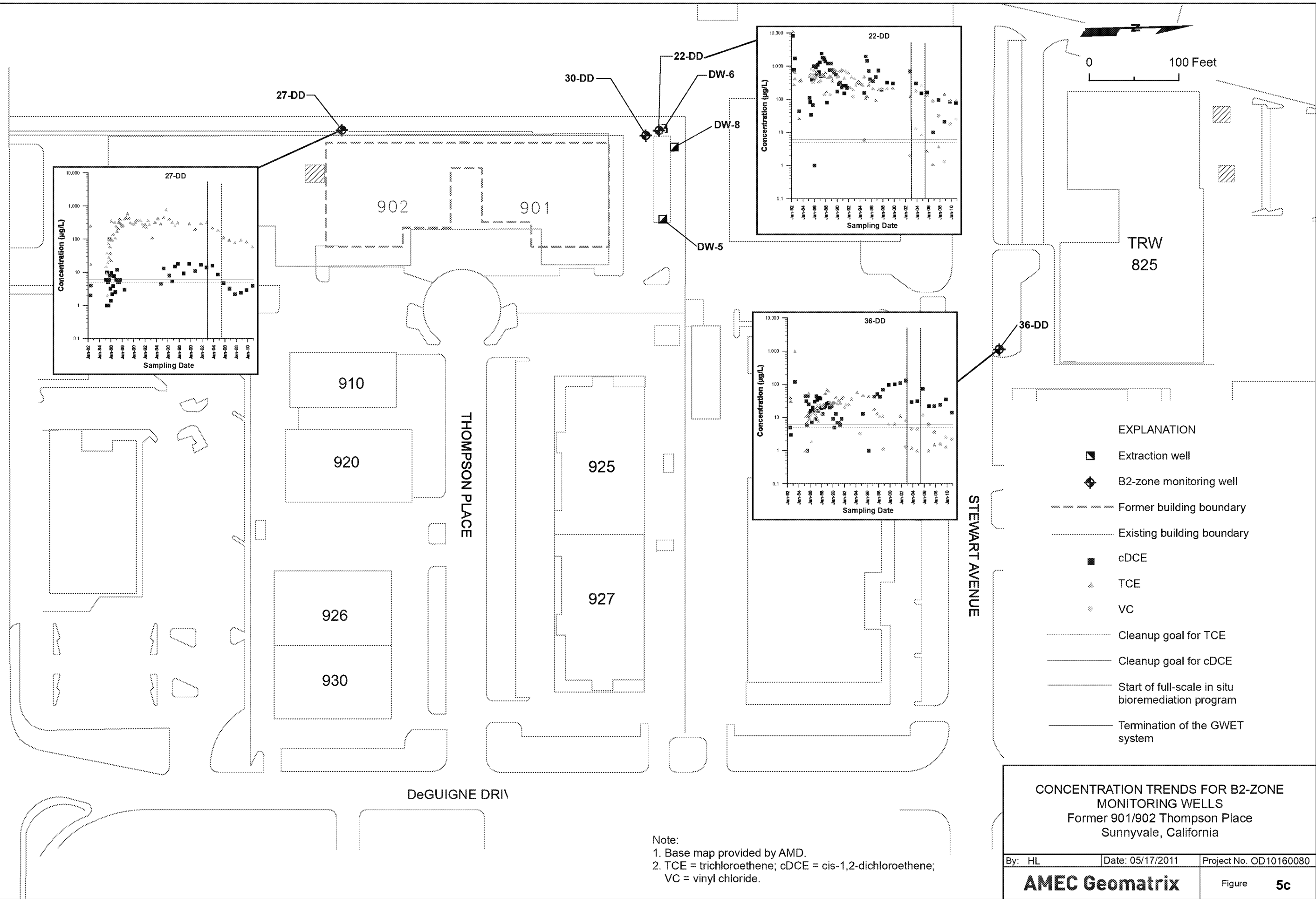
By: HL Date: 05/17/2011 Project No. OD10160080

AMEC Geomatrix Figure 5a

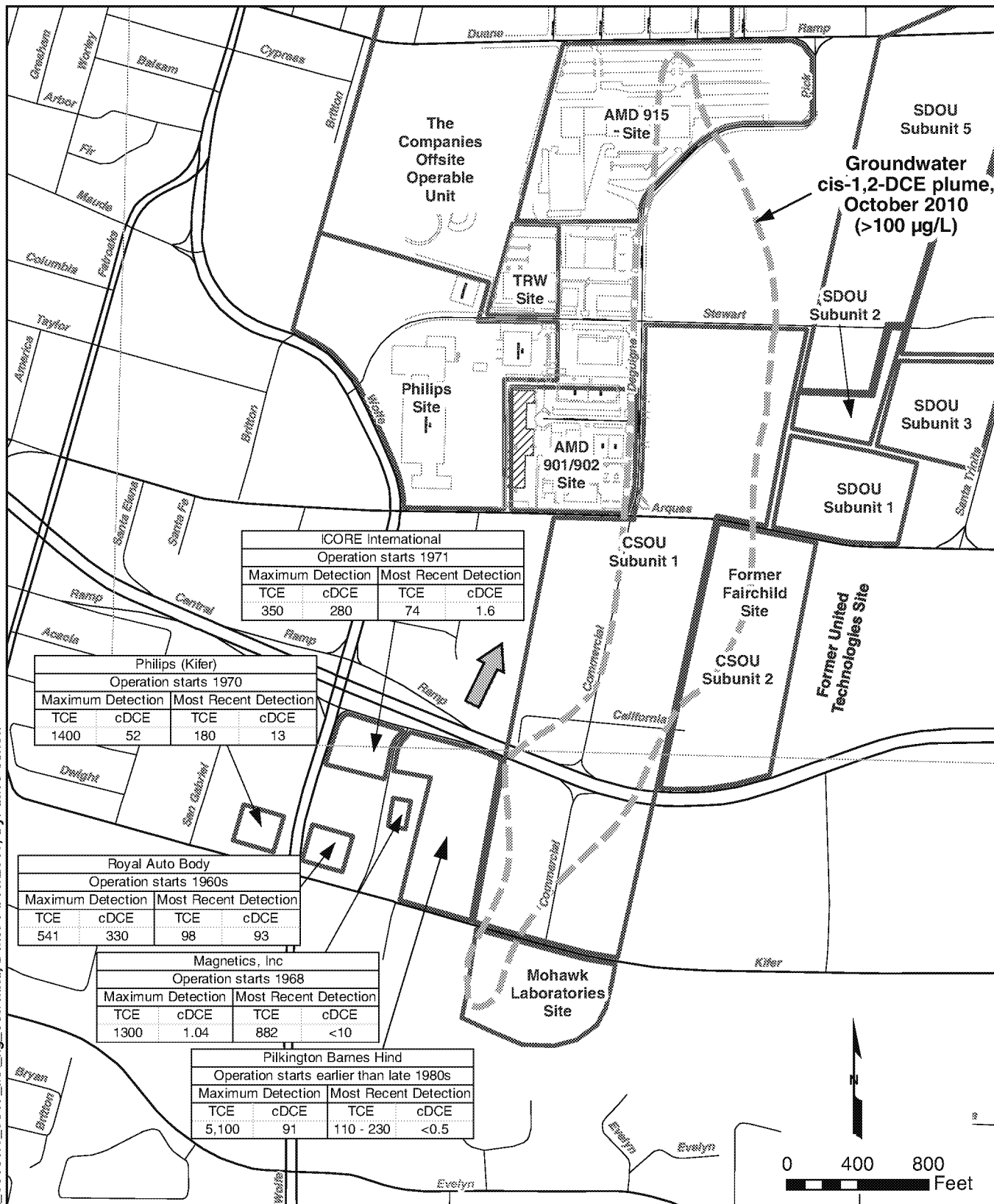
Notes:  
1. Base map provided by AMD.  
2. TCE = trichloroethene; cDCE = cis-1,2-dichloroethene;  
VC = vinyl chloride.

File path: S:\OD\10160080\task\_0003111\_0317\_fs\fig\_05b.mxd; Date: 05/17/2011; By: kristin.uber





Note:  
1. Base map provided by AMD.  
2. TCE = trichloroethene; cDCE = cis-1,2-dichloroethene;  
VC = vinyl chloride.



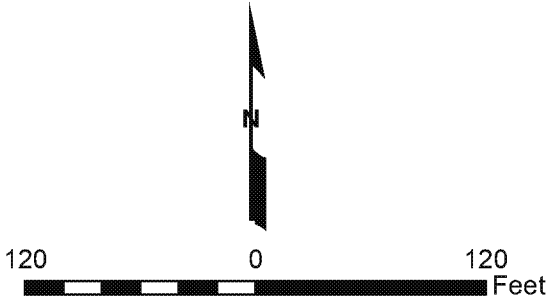
File path: S:\OD10160080\task\_000311\_0317\_fig\_06a.mxd; Date: 04/19/2011; By: dave.oshea

File path: S:\OD10160080\task\_000311\_0317\_ffs\fig\_06b.mxd; Date: 04/14/2011; By: irene.skolnik



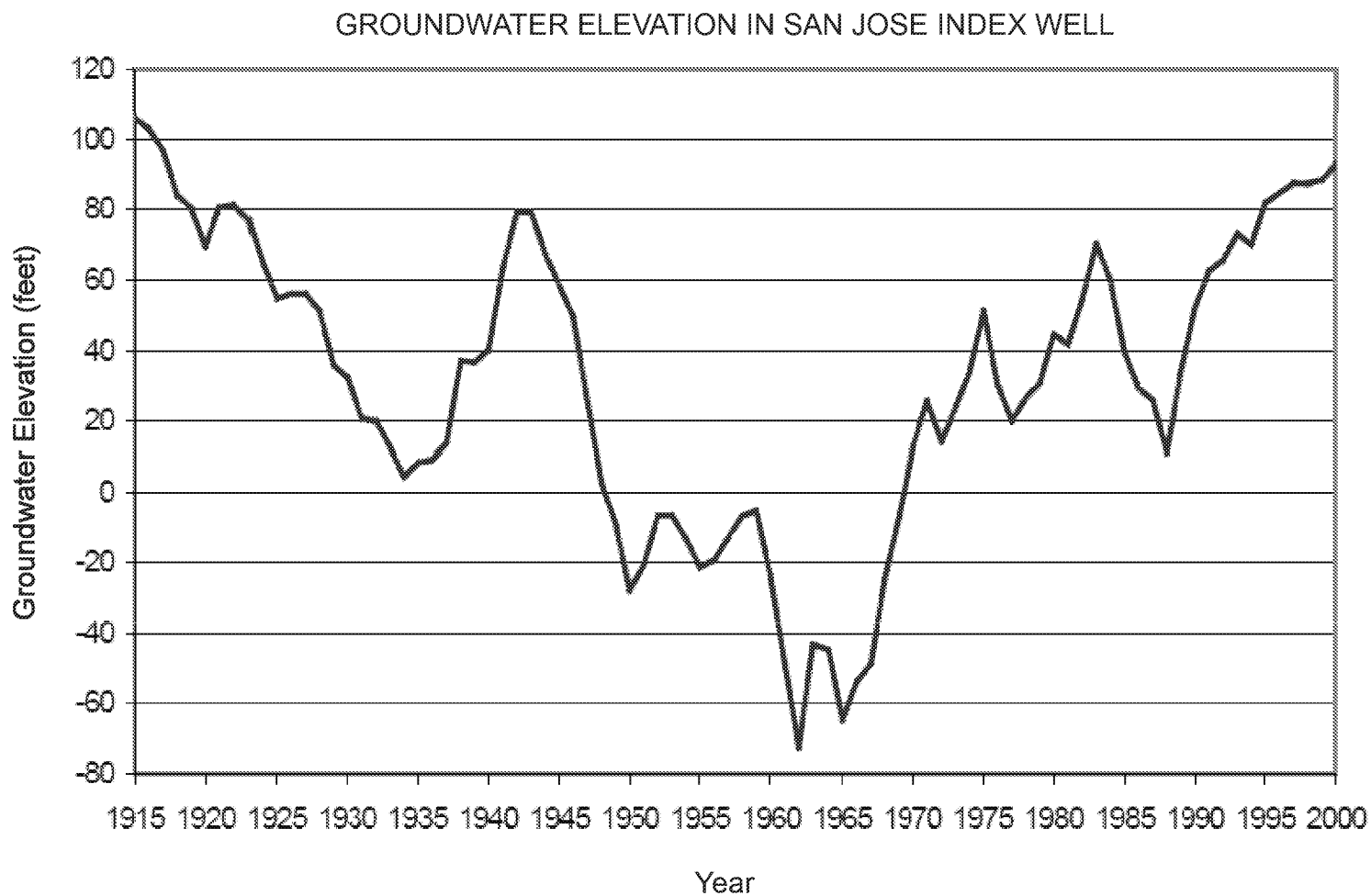
- EXPLANATION
- Monitoring well
  - cDCE
  - TCE
  - VC
  - Cleanup goal for TCE
  - Cleanup goal for cDCE
  - Start of full-scale in situ bioremediation program

Notes:  
1. TCE = trichloroethene; cDCE = cis-1,2-dichloroethene; VC = vinyl chloride.  
2. Only those wells located near the southern boundaries of the 901/902 Thompson Place and Philips sites are shown.



CONCENTRATION TRENDS FOR SELECTED MONITORING WELLS  
Former 901/902 Thompson Place  
Sunnyvale, California

By: MC	Date: 04/14/2011	Project No. OD10160080
AMEC Geomatrix		Figure 6b



HISTORICAL GROUNDWATER FLUCTUATION IN  
THE SANTA CLARA VALLEY SUBBASIN  
Former 901/902 Thompson Place  
Sunnyvale, California

By: HL	Date: 04/14/2011	Project No. OD10160080
--------	------------------	------------------------

**AMEC Geomatrix**

Figure **6c**

Reference: Santa Clara Valley Water District Groundwater Management Plan (SCVWD, 2001)

---

**APPENDIX A**

Summary of Historical COC Concentrations in Pumping and  
Monitoring Wells







APPENDIX A-1

HISTORICAL TRICHLOROETHENE CONCENTRATIONS IN GROUNDWATER

Former 901/902 Thompson Place  
Sunnyvale, California

Results reported in micrograms per liter (mg/L)

Well ID	Jan-90	Apr-90	Jul-90	Oct-90	Jan-91	Apr-91	Jul-91	Oct-91	Jan-92	Apr-92	Jul-92	Oct-92	Jan-93	Apr-93	Jul-93	Oct-93	Jan-94	Apr-94	Jul-94	Oct-94	Jan-95	Apr-95	Jul-95	Oct-95	Apr-96	Oct-96	Apr-97	Oct-97	Apr-98	Oct-98	May-99	Oct-99	Jan-00	Oct-00	Oct-01	Oct/Nov-02	Oct-03		
Extraction Wells																														1900	1600	2200	1400	910	1800	1100	1400	730	13000
DW-1 (B1)																																							
DW-2 (A)																																							
DW-3 (A/B1)																									210		190	180			190								
DW-4 (A)																									120		95	170			240	260	71	280	250	250	29		
DW-5 (B2)																									74		78	75		93	52	86		110	100	110	61		
DW-6 (B2)																									390		230	230			210	280		190	240	240	210		
DW-7 (B1)	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	790	400		520		390	440	460	370	420	110	390	330	240	250	220			230	240		210	250	210	250		
DW-8 (B2)	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	21	12	240	160	280	290	270	350	350	240	240	330	250	240	200			260	230	230		210	250	270	270		
A-Aquifer																																							
14-S										ND	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		ND	ND		ND	ND		ND		ND	ND	ND	ND	ND	
15-S														ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		ND	ND		ND										
16-S		ND			38	45	56			67	69	50	NS	64	81	60	60	61	58	86	42	1.2	52	84	85	38	46	50		34		44		33	25	43	8.9		
17-S										ND			ND	ND	2	ND	ND	ND	2	1	1	ND	ND		2.2		1.9	4.4		10		15		14	22	38	41		
21-S	490									220	710	ND	1090	670	570	400	400	450	480	530	370	340	460	920	380	320	340	290		190		230							
22-S											110		44	140	82	94	68	62	100	120	84	91	100	120	68	94	130	120		70		38		27	26	33	71		
23-S											15	6	8	12	36	10	33	30	16	10	20	37	28	40	45	7	14	22			16		6.3	3.1	9.4	17			
25-S															28		4	10	2	50	8	7.5	4.7	11	11	14	87	74	95	39		32		110	62	84	2.7		
26-S														44	33		39	34	63	86	82	97	380	380	290		120	120											
27-S														440	540	330	450	370	390	670	530	490	620	800	640	750	430	640				810	730	620	680	910	960		
28-S					60					110		140	140	160	160	110	160	210	140	130	130	160	180	220	190	180	370	310		340		550		370	270	330	71		
29-S														110	80	54	39	40	130	190	72	120	140	190	88	110	82	100		95		71		52	30	25	49		
36-S				26		ND			20	50	56	47	62	51	70	60	48	43	39	22	ND	17	24	20	7.9		21	20		7.2		100		83	140	140	100		
37-S														740	610	430	280	400	400	400	310	270	420	410	250		170	260			83		200	150	170	160			
38-S													380	660					950	210	580	630	810	1300	710	370	120	160											
54-S		1		2		2		5		ND	3	15	ND	1	2	1	ND	4	1	1	ND	0.8	1.1	1.2	1.5		1.4	1.5											
28-MW	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
P2A	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
X2A	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
B1-Aquifer																																							
16-D	230	350	300	400	855	840	620	800	820	200	460	150	820	240	500	260	170	120	140	180	120	270	280	270	110	39	80	120			67		56		31	82	130	95	
23-D	1200	1500	1400	1300	1500	970	1400	1100	930	980	1100	810	1200	950	1200	760	1100	950	290	780	460	640	810	710	540	310	340	250		240		300		170	180	200	220		
25-D	390	57	450	500	450	420	400	390	400	120	400	90		730		370		350		350		410		310	63	220	18	200											
27-D	280	420	390	350	350	400	390	320	370	230	370	230		380		290		350		280		260		280	220	190	220	190				200		190	140	190	63		
28-D	73	58	96	97	64	160	210	190	100	86	130	130	130	110	160	120	130	140	120	120	100	120	160	170	140	140	200	150			370	3.2 *	360	470	290	250			
29-D	390	310	570	520	455	550	450	400	410	120	400	380		71		140		390		300		300		300	350	200	91	210		180		150		160	160	58	0.6		
36-D	95	110	120	160	110	110	110	130	110	120	130	100		85				88				56			11		32	52	81	1.1		3.2		110	67	150	110		
52-D	300	240	360	260	440	190	320	180	200	170	330	120		340		92		160		7.1		250		14	45	21	56	0.7		0.7		190		4.2	5.4	24	13		
53-D		ND		ND		1		ND		ND		2.4		4.1			ND				0.6			ND		ND	ND		ND		ND		3.8	4.1	5.6	3.3			
1SB2AR	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
X1B	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
X2B1	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
PMW-1-1	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
PMW-1-2	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI				

APPENDIX A-1

HISTORICAL TRICHLOROETHENE CONCENTRATIONS IN GROUNDWATER

Former 901/902 Thompson Place  
Sunnyvale, California

Results reported in micrograms per liter (mg/L)

Well ID	Oct-04	Oct-05	Oct-06	Oct-07	Oct-08	Oct-09	Oct-10
Extraction Wells							
DW-1 (B1)	16000	18000	540	<13	2.5	<0.5	0.6
DW-2 (A)			5.9	2.3	0.6	<0.5	0.5
DW-3 (A/B1)							
DW-4 (A)	50						
DW-5 (B2)	8.6						
DW-6 (B2)	1.2						
DW-7 (B1)	230	300	1.6	350	17	6.0	5.2
DW-8 (B2)	250	300	240	200			
A-Aquifer							
14-S	ND	ND	ND	ND			
15-S				30	15	13	11
16-S	5.1	3	1	0.9	ND	1	<0.5
17-S	40	42	58	72			
21-S							
22-S	130	190	2.3	6.5	7.8	7.7	16
23-S	25	33	29	52	29	17	9.5
25-S	67	86					
26-S							
27-S	520	480	340	130	280	330	300
28-S		41	1.2	ND	1.6	0.5	<0.5
29-S	84	20	32	16	25	13	18
36-S	91	91	98	70	98	80	75
37-S	110	91	83	81	81	91	60
38-S							
54-S							
28-MW		10	1.5	0.6	0.7	0.6	<0.5
P2A	NI	340	2.5	<0.5			
X2A	NI	200	190	10	<0.5	<0.5	<5.0
B1-Aquifer							
16-D	300	110	1.5	1.7	1.7	7	<1.7
23-D	250	110	3.1	210	300	180	160
25-D							
27-D	25	36	58	120	130	110	110
28-D	11	160	1.3	ND	0.9	1.4	1.5
29-D	1.1	1.3	3.6	53	49	89	35
36-D	85	4.6	92	17	27	19	47
52-D	ND	29	32	37	33	29	35
53-D	1.8	1.2	1.3	5.0	6.9	7	6.9
1SB2AR	NI	NI	NI	3.1			
X1B	NI	360	240	140	100	140	240
X2B1	NI	450	480	8.5	30	71	59
PMW-1-1	NI	3500	3200	<2.5			
PMW-1-2	NI	3	7.7	1.9			
PMW-1-3	NI	<8.3	16	61			
PMW-2-1	NI	82	140	64	58	75	79
PMW-2-2	NI	<20	<2.0	<5.0			
B2-Aquifer							
22-DD	9	2.8	1.1	3.7	140	94	97
27-DD	190	110	93	79	94	83	59
30-DD							
36-DD	0.5	ND	0.8	1.5	1.6	1.3	<0.5
PMW-2-3	NI	290	320	270	250	260	260
B3-Aquifer							
35-DDD	ND	ND	0.5	ND	ND	ND	<0.5

ND	not detected
	not sampled
NI	NI - not installed
	extraction well not operating

Notes

1. For the ISB wells when the sampling event did not happen in October, the maximum concentration of that is used.





APPENDIX A-2

HISTORICAL cis-1,2-DICHLOROETHENE CONCENTRATIONS IN GROUNDWATER  
Former 901/902 Thompson Place  
Sunnyvale, California

Results reported in micrograms per liter (µg/L)

Well ID	Dec-88	Mar-89	Jun-89	Oct-89	Jan-90	Apr-90	Jul-90	Oct-90	Jan-91	Apr-91	Jul-91	Oct-91	Jan 92	Apr 92	Jul 92	Oct 92	Jan 93	Apr 93	Jul 93	Oct 93	Jan 94	Apr 94	Jul 94	Oct-94	Jan-95	Apr-95	Jul-95	Oct-95	Apr-96	Oct-96	Apr-97	Oct-97	Apr-98	Oct-98	May-99			
Extraction Wells																																						
DW-1 (B1)																													1638		980	1400	830	890				
DW-2 (A)																																						
DW-3 (A/B1)	164	33																											31		8.6	17			8.5			
DW-4 (A)	8225	6100																											770		188	410			220			
DW-5 (B2)	ND																												120		56	53		67	20			
DW-6 (B2)	6																												13		11	14			7			
DW-7 (B1)	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	59	81		146		118	115	72	84	98.7	499.4	84	146.6	54	80	86			86		
DW-8 (B2)	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	8	ND	3	2	9	ND	ND	6	5.8	7.1	2.3	ND	7.2	ND	2.8			6	25		
A-Aquifer																																						
14-S	1		ND	ND						ND				ND	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		ND	1.9	2.2	3.5				
15-S		ND	ND	ND										ND	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		ND	ND		ND				
16-S	2800	2800				420			170	180	250			102	174	205		78	84	44	37	37	67	156	68	149	58	150	ND	93	96	90		34				
17-S	ND		ND											ND	ND	ND	ND	ND	ND	ND	ND	ND	0.9	ND	ND	ND	ND	ND	11		55	85		230				
21-S	ND	55	50	120										127	332	32	821	707	703	379	606	518	592	780	543	480	514	330	405	170	391	286		40				
22-S	470														717		394	1616	575	354	386	293	285	331	386	264	204	410	172.3	310	366	194		180				
23-S	3800	2600	1200												558	197	475	741	854	434	797	487	637	985	515	1025	613	888	693	270	299	228						
25-S		ND	ND															6		13	24	16	7	ND	29	8.8	14	5.2	3.5	4.3	5.4	6.6	7					
26-S	10																	170	241		221	260	302	181	15	92	152.1	87	84		47	49						
27-S	40	40																157	171	73	83	34	46	40	25	21	51.1	20	20	ND	21	32		23				
28-S	760		170						62					54		146	660	373	340	336	605	222	525	786	309	577	719	903	644	490	404	387		330				
29-S	4	79	1															3	ND	12	45	7	5	2	0.8	4.7	6.2	ND	3.2	ND	16	5.4		10				
36-S	15	21	17	8		2		1		ND			ND	ND	2	5	2	5	ND	2	1	2	0.6	ND	ND	ND	1.1	ND	ND		6	21		13				
37-S	ND	40		ND														20	21	9	7	8	13	6	25	4.9	6	ND	3.2		7.8	12						
38-S			180	140														684	525				362	151	501	223	222	140	364	550	404	520						
54-S	NI	NI	NI	ND		ND		ND		ND		ND		ND	ND	3	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		ND	ND						
28-MW	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
P2A	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
X2A	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
B1-Aquifer																																						
16-D	1280	1300	650	480	460	850	730	510	455	280	230	810	490	242	616	123	389	1027	598	415	538	352	378	510	278	247	327	220	ND	232	303	236		200				
23-D	1800	3500	2400	790	670	530	620	400	420	520	690	1500	360	494	102	715	2203	1504	663	990	577	430	306	687	733	686	633	460	518	440	562	230		160				
25-D	6	11	8	16	ND	4	18	ND	ND	12	13	ND	8	7	9	3		10		7		7		4		8.8		ND	2.9	2.9	9	5.2						
27-D	ND	ND	ND	ND	ND	14	ND	ND	ND	ND	ND	ND	ND	3	5	7		ND		4		4		2		3.9		ND	2.2	ND	4.8	4.5		2.4				
28-D	1600	1300	1200	770	400	270	250	300	220	245	1830	760	500	92	135	158	795	1720	1538	448	879	696	648	837	550	640	709	864	556	390	459	371						
29-D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3	5	7		2		1		4		4		4.3		ND	4.1	ND	4.7	6.9		4.1				
36-D	40	35	51	8	13	14	14	15	15	15	14	13	11	ND	12	11		4				2				8.6			12		45	92	130	2				
52-D	NI	NI	NI	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3	5	1		6		3		3		ND		3.6		ND	ND	ND	1.3	ND		ND				
53-D	NI	NI	NI	ND		ND		ND		ND		ND		ND		ND		4				ND				0.7			ND		ND	ND		ND				
1SB2AR	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
X1B	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
X2B1	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
PMW-1-1	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
PMW-1-2	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
PMW-1-3	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI		
PMW-2-1	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI																							

APPENDIX A-2

HISTORICAL cis-1,2-DICHLOROETHENE CONCENTRATIONS IN GROUNDWATER  
Former 901/902 Thompson Place  
Sunnyvale, California

Results reported in micrograms per liter (µg/L)

Well ID	Oct-99	Jan-00	Oct-00	Oct-01	Oct/Nov-02	Oct-03	Oct-04	Oct-05	Oct-06	Oct-07	Oct-08	Oct-09	Oct-10
Extraction Wells													
DW-1 (B1)	1504.8		940	890	490	13000	14000	17000	28000	1200	1.6	0.8	1.2
DW-2 (A)									110	5.5	<0.5	1.1	1.1
DW-3 (A/B1)													
DW-4 (A)	230	73	190	140	120	150	87						
DW-5 (B2)	54		140	160	150	28	18						
DW-6 (B2)	11		13	13	22	26	2.1						
DW-7 (B1)	91.5		68	82	88	97	100	100	2000	210	190	69	52
DW-8 (B2)	22		20	15	14	91	18	14	15	8.1			
A-Aquifer													
14-S	ND		21	96	120	160	150	140	130	120			
15-S										2.1	16	6.1	9.3
16-S	66		79	62	60	160	26	27	18	19	4.2	18	6.9
17-S	200		180	180	170	140	90	61	65	57			
21-S	28												
22-S	260		170	150	180	250	190	180	14	27	41	31	25
23-S	220		180	150	170	210	240	96	67	60	130	200	350
25-S	ND		12	40	58	0.6	37	74					
26-S													
27-S	81	57	45	62	72	110	160	75	27	6.4	23	52	79
28-S	708		210	91	83	85		29	3.3	1.5	8.1	18	6.1
29-S	7.9		6.9	3.7	9.3	4	5.3	1.7	1.7	0.8	1.7	1	1.6
36-S	167.7		100	110	70	53	34	22	20	15	13	9.3	11
37-S	147.1		9.7	2.5	3.7	2.9	3.3	5.2	8.5	2.4	3.6	2.2	3.7
38-S													
54-S													
28-MW	NI	NI	NI	NI	NI			26	28	1.1	59	12	10
P2A	NI	NI	NI	NI	NI	NI	NI	200	250	2.7			
X2A	NI	NI	NI	NI	NI	NI	NI	230	840	40	15	10	13
B1-Aquifer													
16-D	23		160	190	170	340	520	140	50	20	2.5	240	180
23-D	220		290	270	220	150	92	74	47	28	8	350	360
25-D													
27-D	ND		3.2	2.5	4.4	71	32	26	15	1.4	2.5	1.5	1.9
28-D	575	199	400	240	280	91	34	54	7.3	2.0	12	10	15
29-D	ND		4.9	2.9	1.6	0.7	ND	ND	72	0.7	0.9	11	1.5
36-D	ND		97	48	90	57	46	1.5	42	6.1	5.8	40	34
52-D	4.2		ND	ND	31	33	1.3	2.1	2.2	1.4	1.7	1	1.8
53-D	ND		ND	ND	ND	4.5	6.9	4.4	0.7	ND	ND	ND	<0.5
1SB2AR	NI	NI	NI	NI	NI	NI	NI	NI	NI	190			
X1B	NI	NI	NI	NI	NI	NI	NI	1600	1100	1700	930	1300	2400
X2B1	NI	NI	NI	NI	NI	NI	NI	420	1600	670	360	1100	470
PMW-1-1	NI	NI	ND	NI	NI	NI	NI	8400	11000	560			
PMW-1-2	NI	NI	NI	NI	NI	NI	NI	930	330	240			
PMW-1-3	NI	NI	ND	NI	NI	NI	NI	1200	2000	7800			
PMW-2-1	NI	NI	NI	NI	NI	NI	NI	6700	7500	6300	4900	5600	6800
PMW-2-2	NI	NI	ND	NI	NI	NI	NI	2100	160	830			
B2-Aquifer													
22-DD	298.5				690	300	150	160	10	96	21	84	78
27-DD	18		11	17	14	16	8.6	4.7	3.2	2.2	2.4	2.9	3.9
30-DD													
36-DD	97		100	110	130	29	31	73	22	22	24	35	14
PMW-2-3	NI	NI	NI	NI	NI	NI	NI	440	480	400	220	160	220
B3-Aquifer													
35-DDD	ND		ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	<0.5

ND	not detected
	not sampled
NI	NI - not installed
	extraction well not operating

Note:  
1. For the ISB wells when the sampling event did not happen in October, the maximum concentration of that year is used.



APPENDIX A-3

HISTORICAL VINYL CHLORIDE CONCENTRATIONS IN GROUNDWATER

Former 901/902 Thompson Place  
Sunnyvale, California

Results reported in micrograms per liter (µg/L)

Well ID	Aquifer Zone	Oct-86	Oct-87	Oct-88	Oct-89	Oct-90	Oct-91	Oct-92	Oct-93	Oct-94	Oct-95	Oct-96	Oct-97	Oct-98	Oct-99	Oct-00	Oct-01	Oct-02	Oct-03	Oct-04	Oct-05	Oct-06	Oct-07	Oct-08	Oct-09	Oct-10										
Extraction Wells																																				
DW-1	B1	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	250	34	61	19	22	270	540	500	490	NS	820	40	1.5	3.1										
DW-2	A												NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	<0.7	0.7	1	1.1	<0.5	
DW-4	A												<100	<100	<100	<100	<100	<100	<100	<100	45		17	21	14	8.6	120	98	NS	NS	NS	NS	NS	NS	NS	NS
DW-5	B2												NS	NS	NS	NS	NS	NS	NS	NS	12	5.4	5.3	15	14	7.4	1.1	0.7								
DW-6	B2																				<2.5	NS	<20	<1	<0.8	<1.0	1.6	11								
DW-7	B1												NS	NS	NS	NS	NS	NS	NS	NS	4.4	ND	<5	4.9	NS	<20	2.9	2.4	1.7	3.2	2.8	4.6	230	14	70	110
DW-8	B2	ND	ND	<5	NS	<1.0	<20	<2	<0.7	<1.3	2.7	<2.0									<1.7	<1.7	<1.7	NS	NS	NS										
A-Aquifer																																				
14-S	A	<100	<100	<100	<100	<100	<100	<100	<100	ND	ND	NS	<0.5	<0.5	<10	<1.0	<1.0	<0.5	<0.5	<1.0	<1.0	<1.0	<1.0	NS	NS	NS										
15-S	A	NS	NS	NS	NS	NS	NS	NS	NS				<0.5	<0.5	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	<0.5	<0.5	<0.5	<0.5							
16-S	A	470	<100	<100	<100	<100	<100	<100	<100	36	45	8	18	3.1	9.5	19	23	12	190	32	37	130	27	3.9	26	21										
17-S	A	1200	<100	<100	<100	<100	<100	<100	<100	ND	ND	NS	<0.5	<0.5	<10	<1.4	<0.7	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	NS	NS	NS										
22-S	A	<100	210	150	<100	<100	<100	<100	<100	15	43	19	8.9	7.1	<25	2.9	<0.7	1.9	11	6.3	7.3	3.4	15	11	4.4	2.4										
23-S	A	<100	170	530	<100	<100	<100	<100	330	580	510	42	62	NS	26	37	55	34	80	51	42	14	25	23	11	160										
25-S	A	NS	NS	NS	NS	NS	NS	NS	NS	1.6	ND	<2	<0.5	0.8	<10	<1	4.1	2.8	<0.5	2.3	4.4	NS	NS	NS	NS	NS										
27-S	A									ND		<20	<5.0	<0.5	<10	<6.3	<2.5	<3.6	8.0	10	<3.6	<2.5	<1.0	<1.7	<1.7	<2.5										
28-S	A	340	1600	190	<100	<100	<100	<100	<100	67	160	69	64	13	42	10	<1.3	2.3	140	NS	20	2.6	1.0	7.5	66	77										
29-S	A	NS	NS	NS	NS	NS	NS	NS	NS	ND	ND	NS	<10	<1.2	<0.5	<10	<1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5										
36-S	A												NS	<0.5	<0.5	<10	<1	<0.5	<0.5	1.1	<0.5	<1.0	<0.5	<0.7	<0.5	<0.5										
37-S	A	<100	<100	<100	<100	<100	<100	<100	<100	ND	ND	NS	<2.5	NS	<10	1.8	<0.5	<0.7	<0.6	<0.7	<0.7	<0.5	<0.5	<0.5	<0.5	<0.5										
28-MW	A	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NS	NS	NS	28	38	1.0	4.3	43	73										
P2A	A																	NS	5.4																	
X2A	A																	62	350	210	880	360	850													
B1-Aquifer																																				
16-D	B1	450	220	160	<100	<100	<100	<100	<100	48	55	40	49	18	29	22	9.9	12	14	31	45	59	150	4.5	110	180										
23-D	B1	1200	280	500	<100	<100	<100	<100	<100	140	42	<5	<5.0	<2.5	<25	5.9	6.2	8.2	19	8.9	8.3	21	2.4	<2.5	41	52										
27-D	B1	NS	NS	NS	NS	NS	NS	NS	NS	ND	ND	<20	<1.2	<0.5	<17	<1	<0.5	<0.7	57	11	5.7	13	<1.3	<1.0	<1.0	<1.0										
28-D	B1	740	460	300	190	140	220	<100	<100	210	140	20	75	NS	43	35	6.9	23	10	13	15	6.2	1.6	7.8	22	90										
29-D	B1	NS	NS	NS	NS	NS	NS	NS	NS	ND	ND	<10	<2.5	<0.5	<10	<1	<0.7	<0.5	10	2.5	5.2	24	<0.5	<0.5	<0.5	<0.5										
36-D	B1									NS	NS	NS	<0.5	<0.5	<10	<1	<0.5	<0.5	0.9	2.4	0.5	0.6	<0.5	<0.5	<0.5	<0.5										
52-D	B1									ND	ND	<2	<0.5	<0.5	<10	<1	<0.5	<0.7	6.5	1.4	0.6	<0.5	<0.5	<0.5	<0.5	<0.5										
53-D	B1									NS	NS	NS	<0.5	<0.5	<10	<1	<0.5	<0.5	<0.5	<0.5	<0.5	4.0	<0.5	<0.5	<0.5	<0.5										
1SB2AR	B1	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	84	NS	NS	NS										
X1B	B1																				120	110	350	240	400	49										
X2B1	B1																				41	130	560	200	510	690										
PMW-1-1	B1																				410	580	850	NS	NS	NS										
PMW-1-2	B1																				730	280	360													
PMW-1-3	B1																				90	560	900													
PMW-2-1	B1	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	2300	2800	2600	1700	1500	1800										
PMW-2-2	B1																				310	730	2300	NS	NS	NS										
B2-Aquifer																																				
22-DD	B2	1300	140	140	<100	<100	<100	120	<100	5.9	ND	<12	<2.5	<2.5	<20	NS	NS	2.0	13	260	130	88	32	1.3	18	25										
27-DD	B2	NS	NS	NS	NS	NS	NS	NS	NS	ND		<5	<2.5	<1.0	<25	<2	<0.8	<1.3	<0.8	<1.3	<0.7	<0.5	<0.7	<0.5	<0.5	<0.5										
36-DD	B2									3.2		NS	NS	<0.5	1.1	<10	<1	<0.5	1.3	4.6	4.5	12	6.2	3.6	1.6	2.5	2.2									
PMW-2-3	B2	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	NI	24	32	40	20	13	21										
B3-Aquifer																																				
35-DDD	B3	NS	NS	NS	NS	NS	NS	NS	NS	ND	ND	<0.5	<0.5	<0.5	<10	<1	<0.5	<0.5	0.7	0.7	1.5	<0.5	<0.5	<0.5	<0.5	<0.5										

Abbreviations

ND = not detected

NI = not installed

NS = not sampled

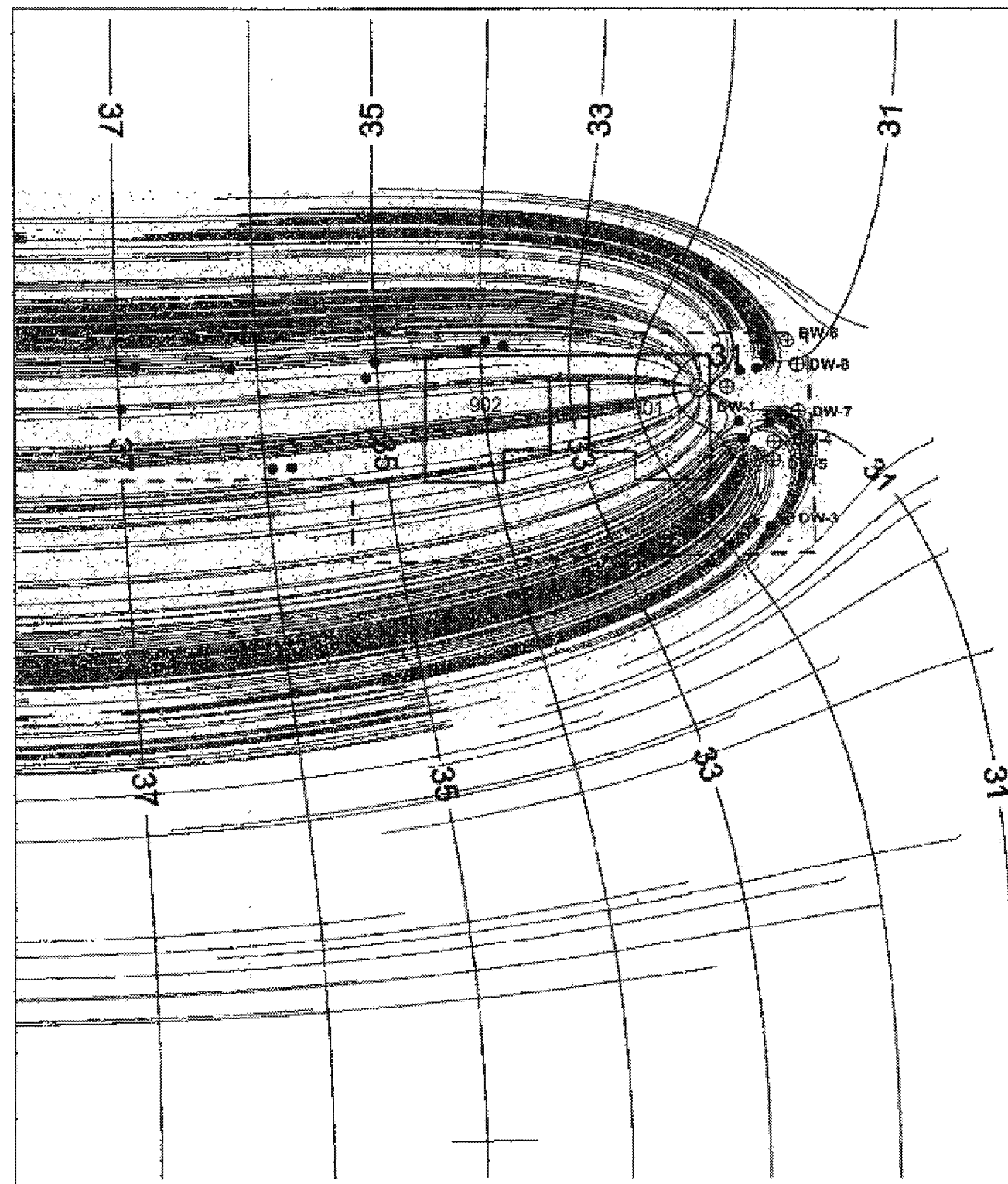
---

**APPENDIX B**


Simulated Capture Zones Provided in the Second Five-Year Report



DWG DATE: 3/28/01 PROJECT NO: RC000520.000-1.1 NO. AND 90' / 20' DRAWING. 1  
CHECKED: SBR APPROVED: STP DRAFTED: SBR



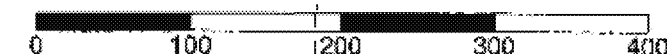
### Legend

- Monitoring Well
- ⊕ DW-8 Extraction Well
- - - Property Boundary
- 32- Water Table Contour
- Particle Pathline
-  Capture Zone

### System Extraction Rates

Well	Rate (gpm)	Unit
DW-1	2.83	A/B1
DW-2	0.0	A/B1
DW-3	7.52	A/B1
DW-4	0.88	A
DW-5	0.04	B2
DW-6	7.96	B2
DW-7	2.06	B1
DW-8	12.54	B2

Feet



ESTIMATED CAPTURE ZONE-1995  
A-AQUIFER

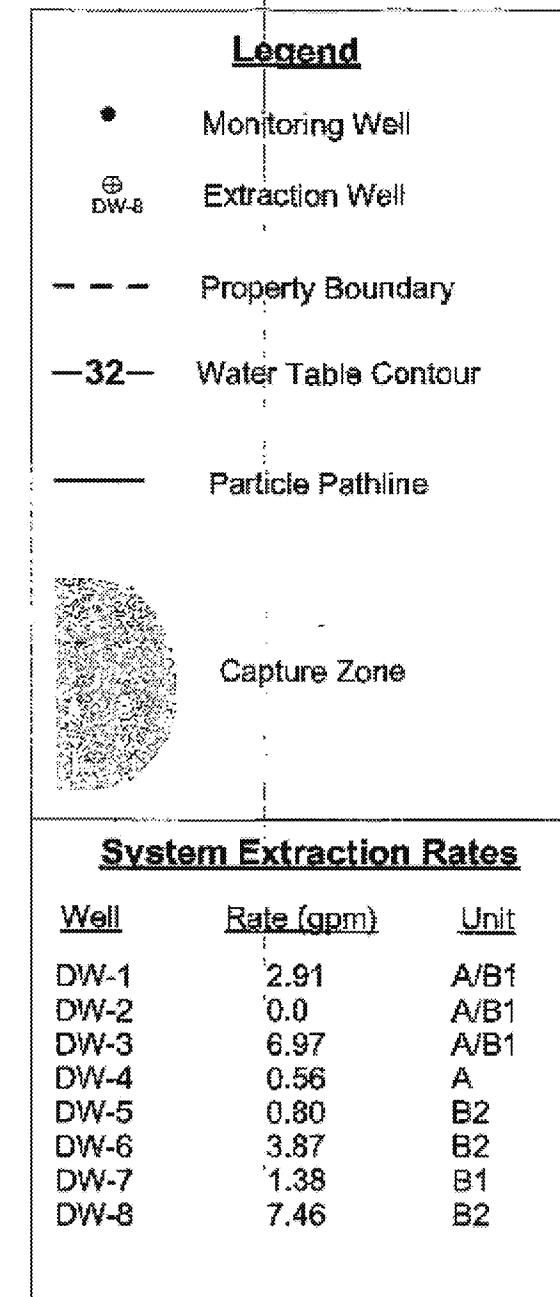
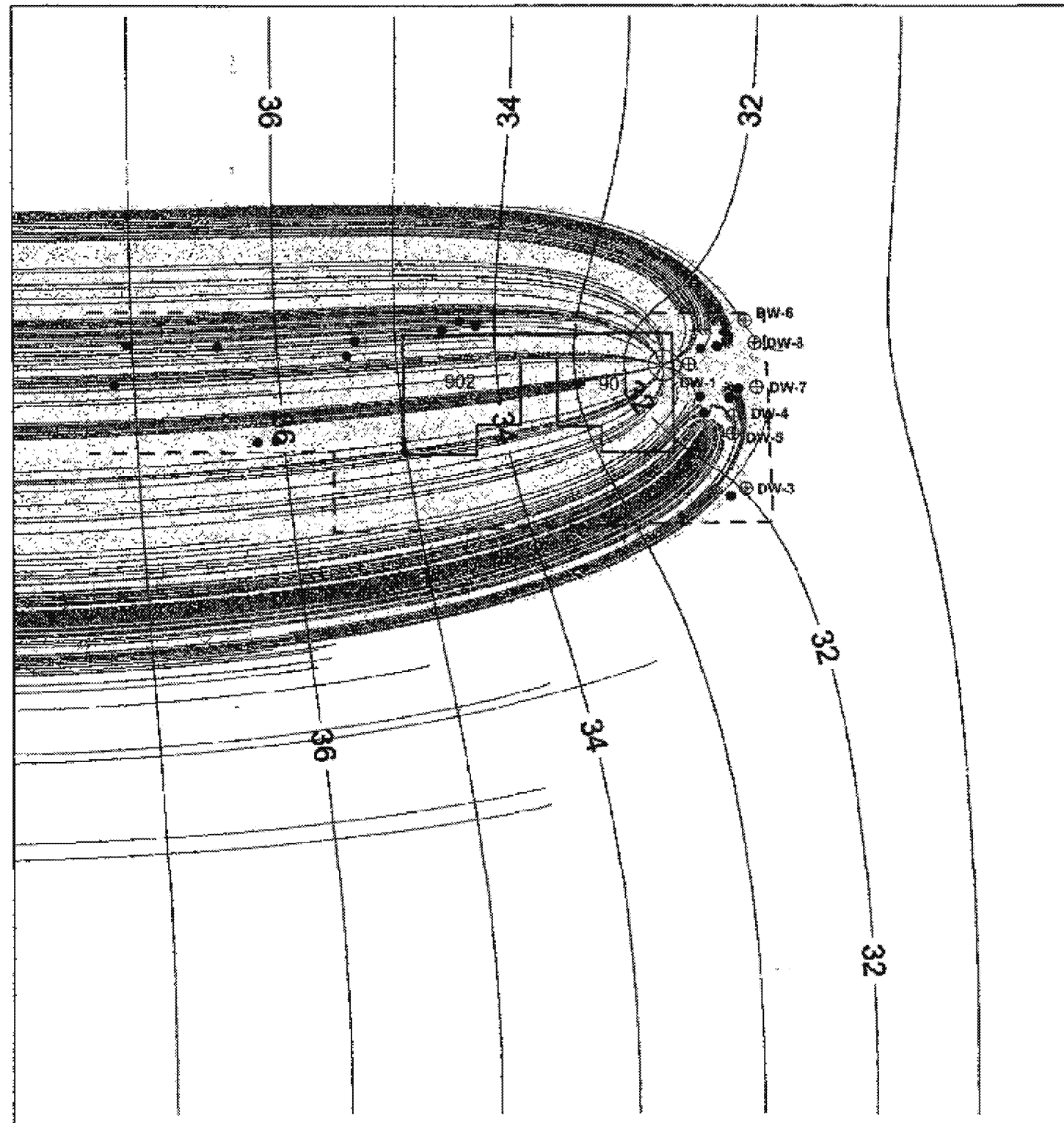
Advanced Micro Devices, Inc.  
Sunnyvale, California

FIGURE

14



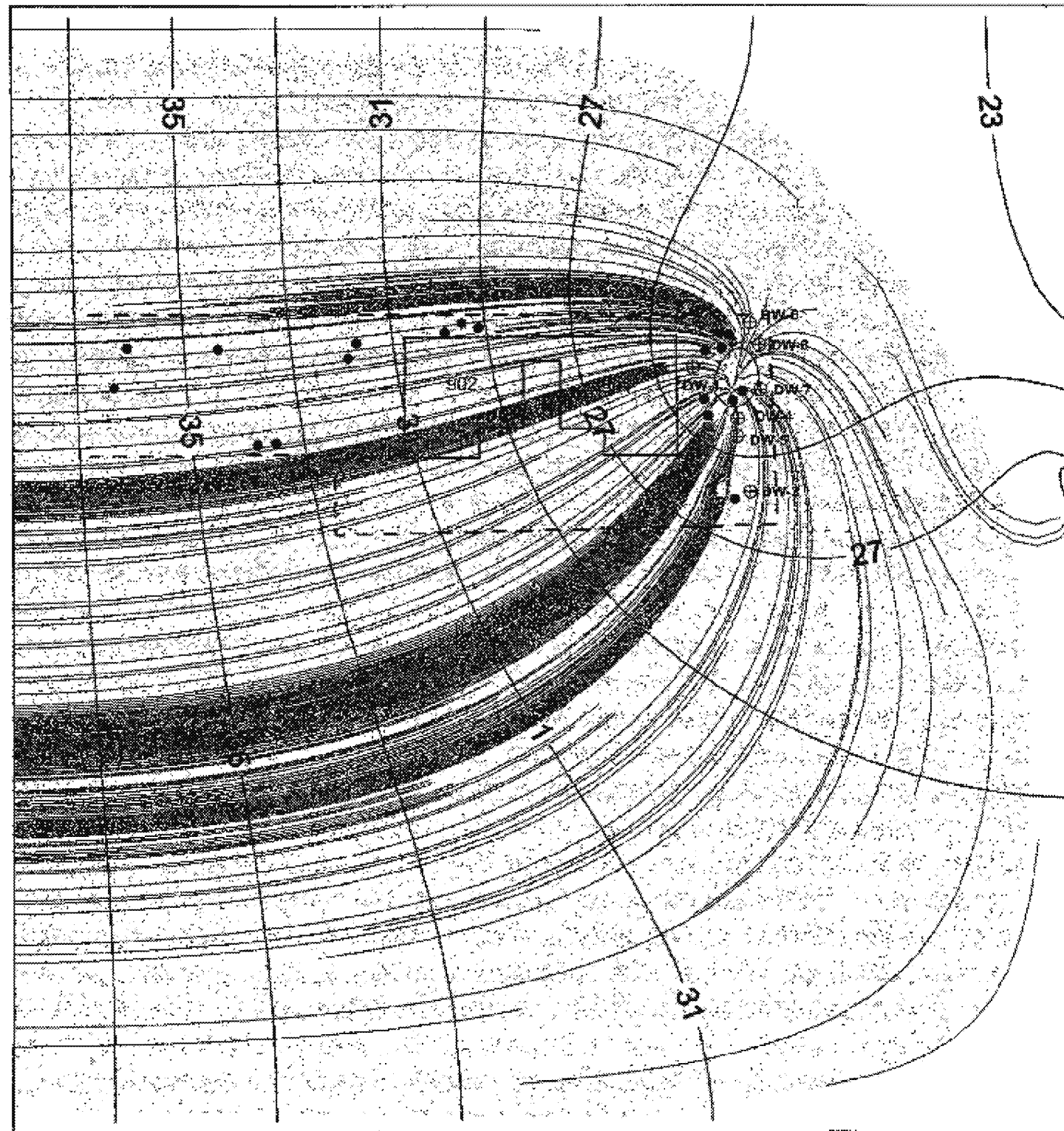
DWG DATE: 3/28/01 PROJECT NO: 40000520.000 FILE NO: AND 303/303 DRAWING 4  
CREATED: SER  
APPROVED: STP  
CHECKED: SBR




ESTIMATED CAPTURE ZONE-2000/2001  
A-AQUIFER

Advanced Micro Devices, Inc.  
Sunnyvale, California

FIGURE  
15



**Legend**

- Monitoring Well
- ⊕ DW-8 Extraction Well
- - - Property Boundary
- 32- Water Table Contour
- Particle Pathline
-  Capture Zone

**System Extraction Rates**

Well	Rate (gpm)	Unit
DW-1	2.83	A/B1
DW-2	0.0	A/B1
DW-3	7.52	A/B1
DW-4	0.88	A
DW-5	0.04	B2
DW-6	7.96	B2
DW-7	2.06	B1
DW-8	12.54	B2



ESTIMATED CAPTURE ZONE-1995  
B1-AQUIFER

Advanced Micro Devices, Inc.  
Sunnyvale, California

FIGURE  
16

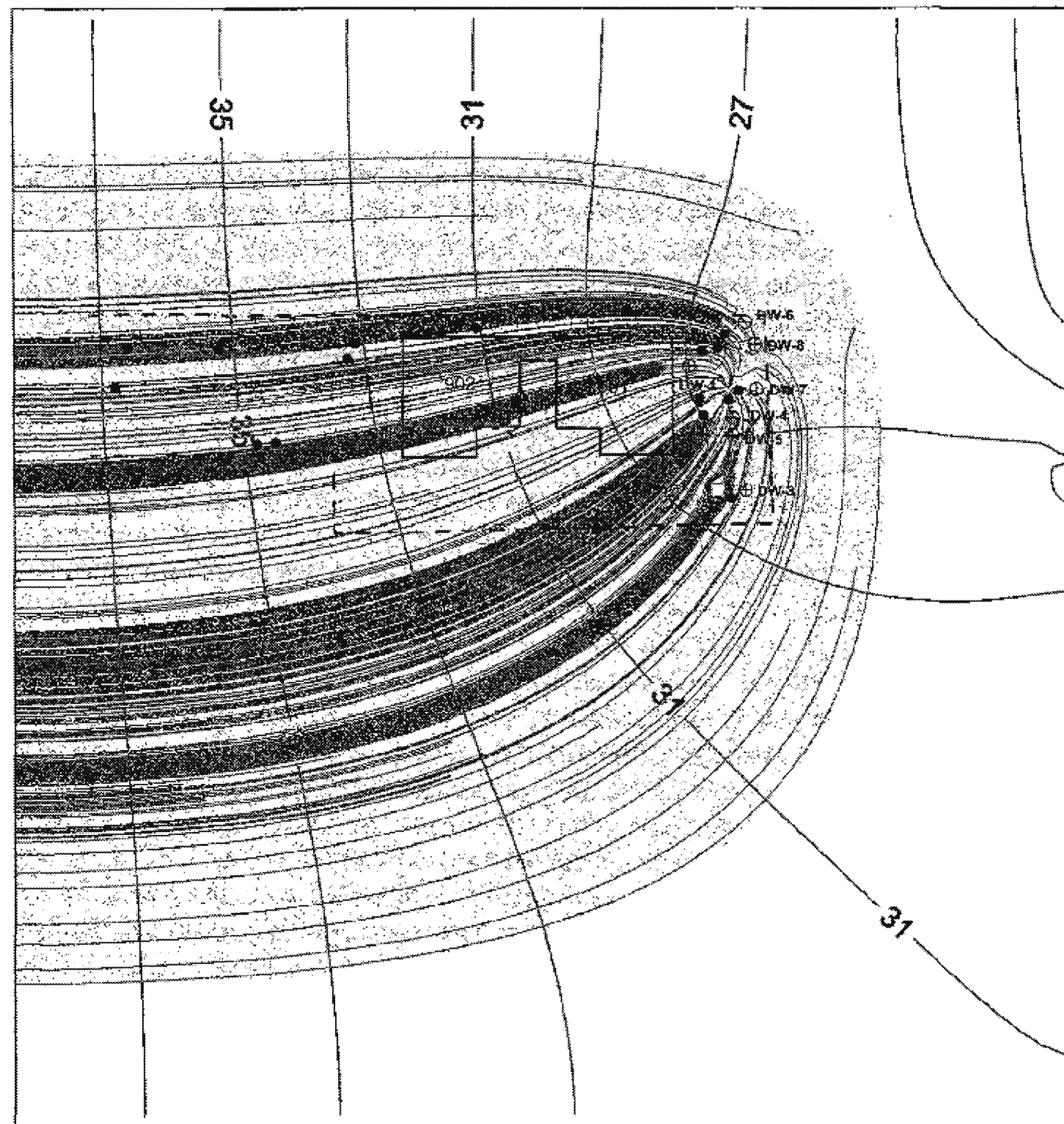
DRAFTED: SKK

APPROVED: STP


CHECKED: STP

PROJECT NO: HCD00000000 FILE NO. AND 801/902 DRAWING: 5

DWG DATE: 3/28/01



### Legend

- Monitoring Well
- ⊕  
DW-8 Extraction Well
- - - Property Boundary
- 32- Water Table Contour
- Particle Pathline
-  Capture Zone

### System Extraction Rates

Well	Rate (gpm)	Unit
DW-1	2.91	A/B1
DW-2	0.0	A/B1
DW-3	6.97	A/B1
DW-4	0.56	A
DW-5	0.80	B2
DW-6	3.87	B2
DW-7	1.38	B1
DW-8	7.46	B2

Feet

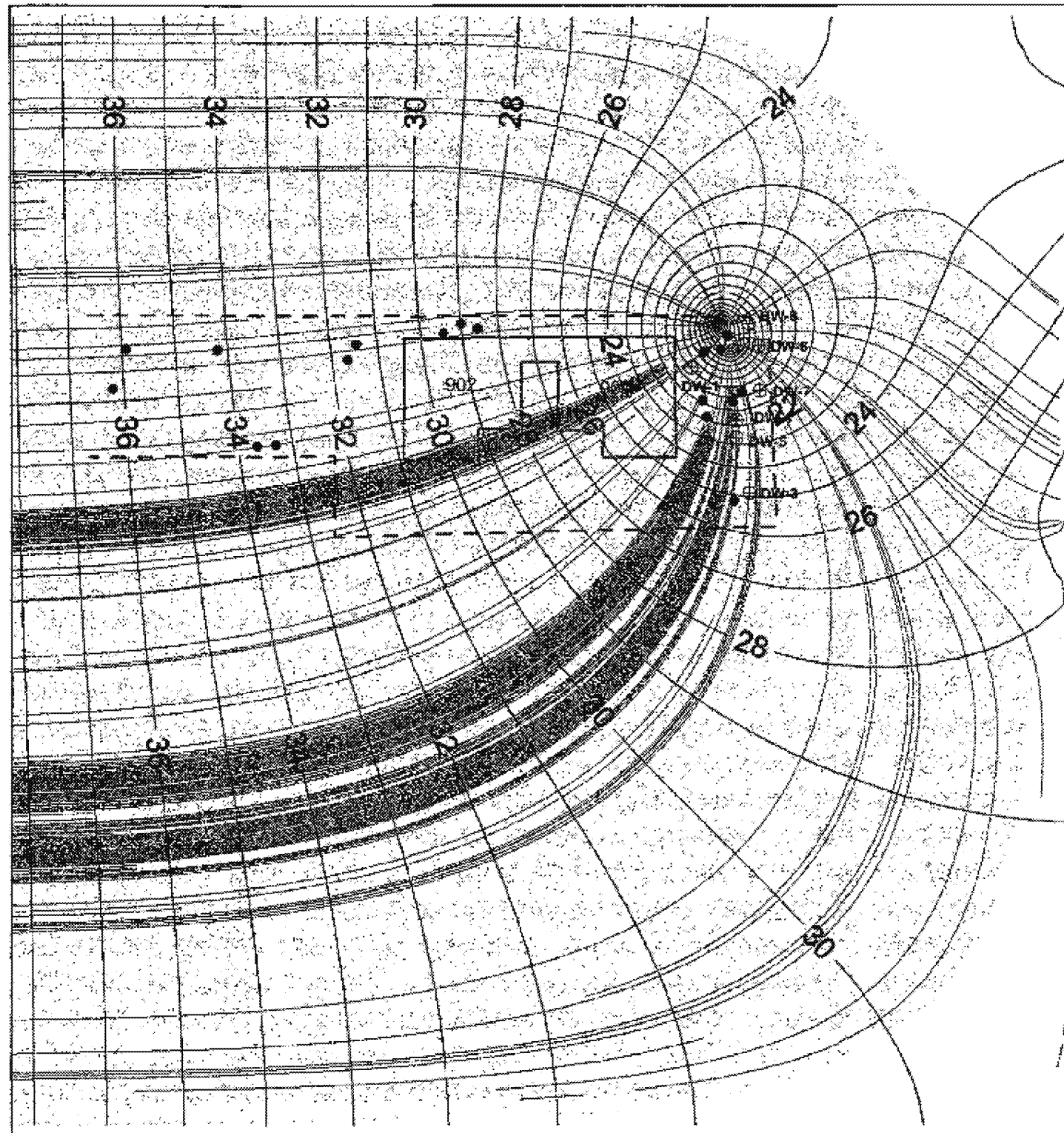


ESTIMATED CAPTURE ZONE-2000/2001  
B1-AQUIFER

Advanced Micro Devices, Inc.  
Sunnyvale, California

FIGURE

17



**Legend**

- Monitoring Well
- ⊕ DW-8 Extraction Well
- - - Property Boundary
- 32- Water Table Contour
- Particle Pathline
- Capture Zone

**System Extraction Rates**

Well	Rate (gpm)	Unit
DW-1	2.83	A/B1
DW-2	0.0	A/B1
DW-3	7.52	A/B1
DW-4	0.88	A
DW-5	0.04	B2
DW-6	7.96	B2
DW-7	2.06	B1
DW-8	12.54	B2

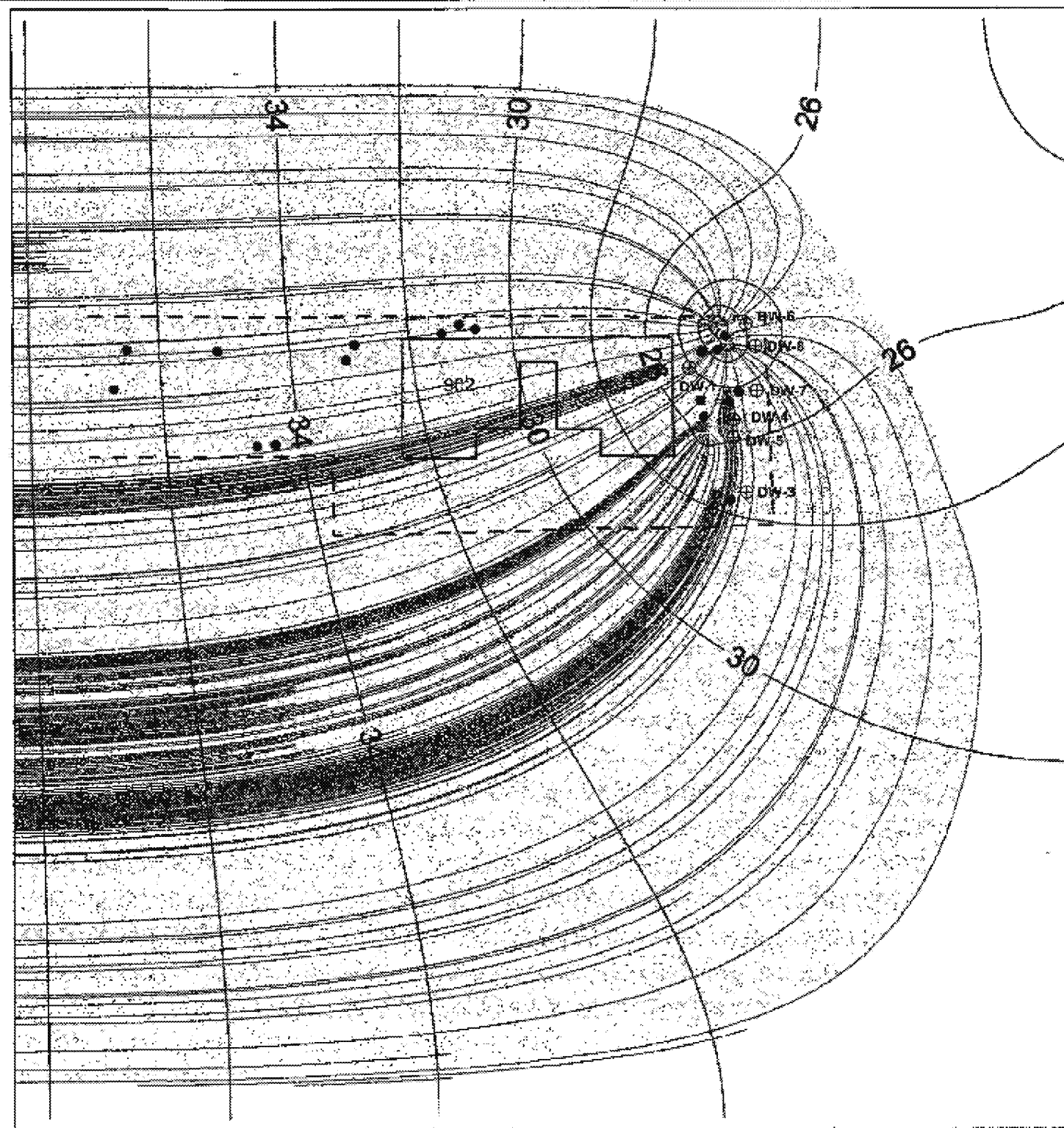


**ESTIMATED CAPTURE ZONE-1995  
B2-AQUIFER**

Advanced Micro Devices, Inc  
Sunnyvale, California



DWG DATE: 3/28/01  
 PROJECT NO. 90000520.00  
 FILE NO. A0001/002  
 DRAWING NO. 0  
 CHECKED: SB3  
 APPROVED: STP  
 DRAFTED: SB9



# ESTIMATED CAPTURE ZONE-2000/2001 B2-AQUIFER

Advanced Micro Devices, Inc.  
 Sunnyvale, California

## Legend

- Monitoring Well
- ⊕ DW-8 Extraction Well
- - - Property Boundary
- 32- Water Table Contour
- Particle Pathline
- Capture Zone

## System Extraction Rates

Well	Rate (gpm)	Unit
DW-1	2.91	A/B1
DW-2	0.0	A/B1
DW-3	6.97	A/B1
DW-4	0.56	A
DW-5	0.80	B2
DW-6	3.87	B2
DW-7	1.38	B1
DW-8	7.46	B2



FIGURE

19

---

## APPENDIX C

### Development of Groundwater Risk Based Concentrations for Vapor Intrusion Pathway

## TABLE OF CONTENTS

		Page
1.0	INTRODUCTION.....	1
2.0	CHEMICAL SELECTION FOR RBC DEVELOPMENT .....	2
3.0	DEVELOPMENT OF GROUNDWATER RBCS .....	3
3.1	FORMULA USED TO CALCULATE GROUNDWATER RBCS.....	3
3.2	MODEL INPUTS.....	3
3.3	ATTENUATION FACTOR RESULTS.....	4
3.4	COMPARISON BETWEEN RBCs CALCULATED BASED ON U.S. EPA's RSLs AND WATER BOARD'S ESLs .....	4
4.0	PROPOSED GROUNDWATER RBCS FOR ACHIEVING VAPOR INTRUSION PROTECTION .....	5
5.0	REFERENCES .....	5

## TABLES

Table C-1	Comparison of Maximum Shallow Groundwater Concentrations and Regulatory Screening Levels
Table C-2	Toxicity Values and Calculated Risk-Based GW Concentrations
Table C-3	Comparison of Proposed Risk-Based GW Concentrations and Regulatory Screening Levels

## FIGURES

Figure C-1a	Transfer Factor Calculation – Input Sheet for PCE
Figure C-1b	Chemical Properties Sheet for PCE
Figure C-1c	Intermediate Calculations Sheet for PCE
Figure C-2a	Transfer Factor Calculation – Input Sheet for TCE
Figure C-2b	Chemical Properties Sheet for TCE
Figure C-2c	Intermediate Calculations Sheet for TCE
Figure C-3a	Transfer Factor Calculation – Input Sheet for cDCE
Figure C-3b	Chemical Properties Sheet for cDCE
Figure C-3c	Intermediate Calculations Sheet for cDCE
Figure C-4a	Transfer Factor Calculation – Input Sheet for VC
Figure C-4b	Chemical Properties Sheet for VC
Figure C-4c	Intermediate Calculations Sheet for VC

## **APPENDIX C**

### **DEVELOPMENT OF GROUNDWATER RISK-BASED CONCENTRATIONS FOR VAPOR INTRUSION PATHWAY**

Former 901/902 Thompson Place  
Sunnyvale, California

#### **1.0 INTRODUCTION**

The California Regional Water Quality Control Board, San Francisco Region ("Water Board"), is the lead agency overseeing remedial activities at the Advanced Micro Devices, Inc. (AMD), 901/902 Thompson Place site (the "site"). The United States Environmental Protection Agency (U.S. EPA) Region 9 Superfund Division provides technical guidance and support to the Water Board.

To address the concern of vapor intrusion exposure nationally, the U.S. EPA has established a set of generic screening levels (GSLs) to preliminarily evaluate the potential of vapor intrusion. The GSLs are derived from empirical data collected in the process of numerous vapor intrusion investigations done in the United States. The Water Board and the U.S. EPA concur that the current site conditions are protective of human health with respect to exposure resulting from vapor intrusion, as stated in the Third Five-Year Review of the site (Water Board, 2009). Nevertheless, both the Water Board and the U.S. EPA still recommend a more site-specific investigation of vapor intrusion potential for the site if the use of the site building changes, given that the concentrations of some chlorinated volatile compounds, such as tetrachloroethene (PCE), trichloroethene (TCE), and vinyl chloride (VC), in shallow groundwater exceed their GSLs (Water Board, 2009).

In order to better evaluate the potential of vapor intrusion, AMEC Geomatrix, Inc. (AMEC), has developed a set of risk-based concentrations (RBCs) in groundwater for the purpose of semi-site-specific screening, using the approach similar to the Tier 2 screening method described in *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils* (U.S. EPA, 2002). The RBCs developed in this appendix may be considered along with chemical-specific applicable or relevant and appropriate requirements (ARARs) and ambient groundwater concentrations to form site-specific remediation goals with respect to vapor intrusion exposure.

The methodology used to develop RBCs is consistent with the following state and federal guidance for risk assessment and calculation of alternative chemical-specific groundwater media cleanup levels:

- Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A) (U.S. EPA, 1989)



- Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals) (U.S. EPA, 1991)
- Supplemental Guidance for Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities (Cal-EPA, 1992)
- Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (U.S. EPA, 2002)
- **User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings** (U.S. EPA, 2004)
- Use of California Human Health Screening Levels (CHHSLs) in Evaluation of Contaminated Properties (Cal-EPA, 2005a)
- Interim Final Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air (Cal-EPA, 2005b)
- Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater (Water Board, 2008)
- User Guide for U.S. EPA Regional 9's **Regional Screening Levels** (U.S. EPA, 2010).

The target excess cancer risk used for the calculation of RBCs for carcinogens was one in one million ( $1 \times 10^{-6}$ ). The target hazard quotient used for the calculation of RBCs for non-carcinogens was 1.

## 2.0 CHEMICAL SELECTION FOR RBC DEVELOPMENT

The medium of concern (i.e. source) for the vapor intrusion pathway is groundwater. As presented in the Third Five-Year Review for the site (U.S. EPA, 2009), among the constituents of concern (COCs) defined in the site Cleanup Requirements Order (Water Board, 1991), only PCE, TCE, and vinyl chloride were found to exceed the residential GSLs. It is noted that the GSL for cis-1,2-dichloroethene (cDCE) was not provided in the Third Five-Year Review and PCE appears to be related to an upgradient, offsite release.

To evaluate whether the pattern of exceedance of groundwater COC concentrations over the GSLs remains the same as that found in the Third Five Year Review, the COC concentrations in shallow groundwater samples collected in October 2010 were also compared with the GSLs (Table C-1). The results indicate that only PCE, TCE, and vinyl chloride exceed the residential GSLs. The groundwater concentrations for other COCs, with the exception of cDCE (no GSL provided), are below the residential screening levels (RSLs), indicating that these COCs in groundwater do not pose human health risks due to exposure through vapor intrusion, even in residential settings.

Recent concentrations of cDCE, an intermediate product of anaerobic reductive dechlorination, have generally been higher in the area of in situ bioremediation at the site. Although cDCE is currently below the environmental screening levels (ESLs) set by the Water

Board, additional substrate addition in the future may elevate cDCE concentrations in shallow groundwater. Therefore, the site-specific RBCs were developed for PCE, TCE, cDCE, and VC.

### 3.0 DEVELOPMENT OF GROUNDWATER RBCS

To better evaluate human health risks associated with the vapor intrusion pathway, a set of semi-site-specific groundwater RBCs was developed based on the Tier 2 evaluation approach described in the *Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils* (U.S. EPA, 2002). The Tier 2 evaluation approach is designed to be used with limited site-specific information, such as soil type and depth to groundwater.

To mitigate inherent uncertainties associated with RBC development, AMEC used conservative assumptions and approaches that would tend to estimate the RBC as lower than it actually needed to be for protection of human health. In general, where uncertainties existed in input parameters, reasonable conservative values were chosen; that is, values that led to higher estimates of exposure were chosen.

#### 3.1 FORMULA USED TO CALCULATE GROUNDWATER RBCs

The semi-site-specific RBCs were estimated using the following equation (U.S. EPA, 2004):

$$RBC_{gw} [\mu g/L] = C_{air} [\mu g/m^3] \times 10^{-3} [m^3/L] \times 1/H \times 1/AF \quad (1)$$

Where:

$RBC_{gw}$  = groundwater screening level

$C_{air}$  = target indoor air concentration

$H$  = dimensionless **Henry's Law** Constant at 23°C [(mg/L—vapor)/(mg/L—water)]

$AF$  = attenuation factor (ratio of indoor air concentration to equivalent soil gas concentration in groundwater)

The target indoor air concentrations for PCE, TCE, and VC were based on the RSLs for indoor air established by the U.S. EPA Regions 1, 3, and 9 (2010). There is no RSL for cDCE, and thus the target indoor air concentrations for cDCE were based on the California Human Health Screening Levels (CHHSLs) for indoor air established by the California Environmental Protection Agency (Cal-EPA; 2005b). The parameters of  $H$  and  $AF$  were obtained from the *Screening-Level Model for Groundwater Contamination*, a version of Johnson and Ettinger spreadsheet model maintained by the Department of Toxic Substances Control (DTSC) under Cal-EPA (DTSC, 2009).

#### 3.2 MODEL INPUTS

The key model inputs were primarily based on conservative default values for California except that the following site and region-specific information were used in the model:

- **Groundwater temperature:** 23 °C – an upper limit of groundwater temperature measured at the site.
- **Depth to groundwater:** eight feet (183 centimeters) – a conservative value based on water levels measured in shallow groundwater.
- **Vadose zone soil type:** loam – a representative type for soils with about 45% to 75% fines (U.S. EPA, 2004). The site vadose zone soil generally contains more fines, ranging from 80% to 95%; therefore, this is a conservative assumption.
- **U.S. Soil Conservation Service (SCS) soil type directly above water table:** same rationale as above.
- **Building ventilation rate:**  $6.78 \times 10^4 \text{ cm}^3/\text{s}$  and  $1.36 \times 10^4 \text{ cm}^3/\text{s}$ , which are equivalent to one- and two-hour<sup>-1</sup> indoor air exchange rates for residences and commercial/industrial buildings, respectively. These ventilation rates have been considered representative for the San Francisco Area (Water Board, 2008).

Figures C-1a and b, C-2a and b, C-3a and b, and C-4a and b show the input and chemical properties pages of the spreadsheet models for PCE, TCE, cDCE, and VC, respectively, for residential settings.

### 3.3 ATTENUATION FACTOR RESULTS

Using the model inputs described above, the spreadsheet model calculated attenuation factors (AFs) for individual constituents and settings. Figures C-1c, C-2c, C-3c, and C-4c show the intermediate calculation sheets of the spreadsheet models for residential settings. The calculated AFs can be found at the cells right below the description “infinite source indoor attenuation coefficient,  $\alpha$  (unitless).” The AFs calculated for residential settings are two times larger than the corresponding values for industrial/commercial settings, because of the difference in building ventilation rates.

### 3.4 COMPARISON BETWEEN RBCs CALCULATED BASED ON U.S. EPA’S RSLs AND WATER BOARD’S ESLs

Using the attenuation factors, dimensionless Henry’s law constants, and Equation 1 presented above, groundwater RBCs for vapor intrusion protection were calculated based on the target indoor air concentrations shown in Table C-2. The resulting RBCs are presented in Table C-2. The calculated RBCs were then compared with the Environmental Screening Levels (ESLs) for vapor intrusion, developed by the Water Board (2008). The results are presented in the third and fourth columns of Table C-3.

It was found that the calculated RBCs were lower than the corresponding ESLs for PCE, TCE, and cDCE. For VC, the calculated RBC was higher than the corresponding ESL. This results because the VC toxicity value used to develop the ESL is larger than that used for developing the RSL.

#### 4.0 PROPOSED GROUNDWATER RBCS FOR ACHIEVING VAPOR INTRUSION PROTECTION

In order to provide better human health protection from potential vapor intrusion, AMEC proposes that the lower values between the RBCs calculated based on the U.S. EPA's RSLs and the Water Board's ESLs be used as the semi-site-specific screening levels for vapor intrusion, as shown in the second column of Table C-3. This set of screening values can be used to help determine whether site groundwater poses an unacceptable human health threat through the vapor intrusion pathway under either residence or industrial/commercial land use scenarios.

#### 5.0 REFERENCES

- California Environmental Protection Agency (Cal-EPA), 1992, Supplemental Guidance for Human Health Multimedia Risk Assessments of Hazardous Waste Sites and Permitted Facilities, Department of Toxic Substances Control Office of Scientific Affairs, July.
- California Environmental Protection Agency (Cal-EPA), 2005a, Use of California Human Health Screening Levels (CHHSLs) in Evaluation of Contaminated Properties, Department of Toxic Substances Control, January.
- California Environmental Protection Agency (Cal-EPA), 2005b, Guidance for the Evaluation and Mitigation of Subsurface Vapor Intrusion to Indoor Air, Interim Final, Department of Toxic Substances Control, February 7.
- California Regional Water Quality Control Board, San Francisco Bay Region (Water Board), 2008, Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater, Interim Final, May.
- California Regional Water Quality Control Board, San Francisco Bay Region (Water Board), 2009, Third Five-Year Review for the Advanced Micro Devices – 901/902 Thompson Place Superfund Site, Sunnyvale, California, September.
- California Department of Toxic Substances Control (DTSC), 2009, Screening-Level Model for Groundwater Contamination: [http://www.dtsc.ca.gov/AssessingRisk/JE\\_Models.cfm](http://www.dtsc.ca.gov/AssessingRisk/JE_Models.cfm), February.
- United States Environmental Protection Agency (U.S. EPA), 1989, Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part A): Office of Emergency and Remedial Response, EPA/540/I-89/002, Interim Final, October.
- United States Environmental Protection Agency (U.S. EPA), 1991, Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals): Office of Emergency and Remedial Response, EPA/540/R-92/003, December.
- United States Environmental Protection Agency (U.S. EPA), 2002, Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils: Office of Emergency and Remedial Response, EPA/530/D-02/004, November.
- United States Environmental Protection Agency (U.S. EPA), 2004, **User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings**: prepared by Environmental Quality Management, Inc., February.

U.S. EPA Regions 3, 6, and 9, 2010, Regional Screening Levels for Chemical Contaminants at Superfund Sites: website, <http://www.epa.gov/reg3hwmd/risk/human/rb-concentration-table/index.htm>, November.

## TABLES

---

**TABLE C-1**  
**COMPARISON OF MAXIMUM SHALLOW GROUNDWATER CONCENTRATIONS AND**  
**REGULATORY SCREENING LEVELS**

Former 901/902 Thompson Place  
Sunnyvale, California

Compound	Maximum Concentration In Shallow Groundwater, October 2010 (µg/L)	CRWQCB-SF Residential ESL (µg/L) <sup>1</sup>	U.S. EPA Residential Vapor Intrusion Screening Level (µg/L) <sup>2</sup>
PCE	17	120	1
TCE	300	530	3
cDCE	350	6,230	NA
tDCE <sup>3</sup>	19	6,730	166
VC	850	4	0
1,1-DCE	<2.5 <sup>4</sup>	6,300	191
1,1-DCA	<2.5	1,000	7
1,1,1-TCA	<2.5	130,000	7,429
Freon 113	<5.0	NA	1,410
1,2-DCB	30	77,000	2,690

**Notes**

1. Environmental screening levels developed by California Regional Water Quality Control Board, San Francisco Region (Water Board, 2009).
2. Based on the values presented in the Third Five-Year Review for the site.
3. Lines shaded gray indicate that maximum concentrations are lower than U.S. EPA groundwater screening levels.
4. "<" indicates constituent not detected above the laboratory reporting limit shown.

**Abbreviations**

PCE = Tetrachloroethene	µg/L = micrograms per liter
1,1-DCE = 1,1-Dichloroethene	1,1,1-TCA = 1,1,1-Trichloroethane
cDCE = cis-1,2-Dichloroethene	1,1-DCA = 1,1-Dichloroethane
TCE = Trichloroethene	1,2-DCB = 1,2-Dichlorobenzene
tDCE = trans-1,2-Dichloroethene	Freon 113 = 1,1,2-Trichloro-1,2,2-trifluoromethane
VC = Vinyl chloride	NA = not available

CRWQCB-SF = California Regional Water Quality Control Board, San Francisco Bay Region  
U.S. EPA = United States Environmental Protection Agency

**TABLE C-2**  
**TOXICITY VALUES AND CALCULATED RISK-BASED GW CONCENTRATIONS**  
 Former 901/902 Thompson Place  
 Sunnyvale, California

Compound	Indoor Air Screening Level (µg/m³)		Dimensionless Henry's Law Constant	AF Based on Conservative Assumptions	Risk-Based GW Concentration Based on RSL (µg/L)
Residential Land Use					
PCE	4.12E-01	(a)	6.78E-01	2.17E-05	2.80E+01
TCE	1.22E+00	(a)	3.67E-01	2.44E-05	1.36E+02
cDCE	7.30E+00	(b)	1.54E-01	2.55E-05	1.86E+03
VC	1.60E-01	(a)	1.05E+00	3.14E-05	4.85E+00
Industrial / Commercial Land Use Only					
PCE	2.10E+00	(a)	6.78E-01	1.09E-05	2.85E+02
TCE	6.10E+00	(a)	3.67E-01	1.22E-05	1.36E+03
cDCE	1.00E+01	(b)	1.54E-01	1.28E-05	5.09E+03
VC	2.80E+00	(a)	1.05E+00	1.57E-05	1.70E+02

**Notes**

- (a) Based on U.S. EPA (2010) RSLs  
 (b) Based on Water Board (2008) ESLs

**Abbreviations**

PCE = Tetrachloroethene  
 cDCE = cis-1,2-Dichloroethene  
 TCE = Trichloroethene  
 VC = Vinyl chloride  
 $\mu\text{g}/\text{L}$  = milligrams per liter  
 $\mu\text{g}/\text{m}^3$  = milligrams per cubic meter

AF = attenuation factor (air concentration ( $\mu\text{g}/\text{L}$ ) / groundwater concentration ( $\mu\text{g}/\text{L}$ )  
 RSL = regional screening level  
 GW = groundwater



**TABLE C-3**

**COMPARISON OF PROPOSED RISK-BASED GW CONCENTRATIONS AND  
REGULATORY SCREENING LEVELS**

Former 901/902 Thompson Place  
Sunnyvale, California

<b>Chemical</b>	<b>Proposed Specific Based GW Concentration (µg/L)</b>	<b>Site Risk- CRWQCB-SF Environmental Screening Level (µg/L)</b>	<b>Risk-Based GW Concentration Based on RSL (µg/L)</b>
<b>Residential Land Use</b>			
PCE	28	120	28
TCE	136	530	136
cDCE <sup>2</sup>	1,860	6,230	1,860
VC	4	4	5
<b>Industrial/Commercial Land Use Only</b>			
PCE	285	420	285
TCE	1,362	1,800	1,362
cDCE <sup>2</sup>	5,090	17,000	5,090
VC	13	13	170

Notes

1. Based on the values presented in the Third Five-Year Review for the site.
2. No values for cDCE; values for tDCE used as surrogate.

Abbreviations

PCE = Tetrachloroethene

µg/L = milligrams per liter

TCE = Trichloroethene

cDCE = cis-1,2-Dichloroethene

VC = Vinyl chloride

CRWQCB-SF = California Regional Water Quality Control Board, San Francisco Bay Region

RSL = regional screening level

U.S. EPA = United States Environmental Protection Agency

GW = groundwater

## **FIGURES**

---

# DATA ENTRY SHEET

GW-SCREEN  
Version 3.0; 04/03

Reset to  
Defaults

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES ☒ x  
OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION  
(enter "X" in "YES" box and initial groundwater conc. below)

YES ☐

DTSC  
Vapor Intrusion Guidance  
Interim Final 12/04  
(last modified 04/09)

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial groundwater conc., $C_g$ ( $\mu\text{g/L}$ )	Chemical
127184		Tetrachloroethylene

ENTER Depth below grade to bottom of enclosed space floor, $L_v$ (cm)	ENTER Depth below grade to water table, $L_{wt}$ (cm)	ENTER SCS soil type directly above water table	ENTER Average soil groundwater temperature, $T_s$ ( $^{\circ}\text{C}$ )
15	152.58	L	23

ENTER Average vapor flow rate into bldg. (Leave blank to calculate) $Q_{avg}$ ( $\text{L/m}$ )
5

ENTER Vadose zone SCS soil type (used to estimate soil vapor permeability)	OR	ENTER User-defined vadose zone soil vapor permeability, $k_v$ ( $\text{cm}^2$ )	ENTER Vadose zone SCS soil type (lookup Soil Parameters)	ENTER Vadose zone soil dry bulk density, $\rho_s^d$ ( $\text{g/cm}^3$ )	ENTER Vadose zone soil total porosity, $n^v$ (unitless)	ENTER Vadose zone soil water-filled porosity, $\theta_w^v$ ( $\text{cm}^3/\text{cm}^3$ )
		1.00E-08	L	1.32	0.399	0.148

ENTER Target risk for carcinogens, $TR$ (unitless)	ENTER Target hazard quotient for noncarcinogens, $THQ$ (unitless)	ENTER Averaging time for carcinogens, $AT_c$ (yrs)	ENTER Averaging time for noncarcinogens, $AT_{nc}$ (yrs)	ENTER Exposure duration, $ED$ (yrs)	ENTER Exposure frequency, $EF$ (days/yr)
1.0E-06	1	70	36	30	350
Used to calculate risk-based groundwater concentration.					

## Transfer Factor Calculation – Input Sheet for PCE

Former 901/902 Thompson Place  
Sunnyvale, California

By: JC Date: 04/12/11 Project No. OD10160080

**AMEC Geomatrix**

Figure **C-1a**

# CHEMICAL PROPERTIES SHEET

Diffusivity in air, $D_a$ (cm <sup>2</sup> /s)	Diffusivity in water, $D_w$ (cm <sup>2</sup> /s)	Henry's law constant at reference temperature, H (atm-m <sup>3</sup> /mol)	Henry's law constant reference temperature, $T_R$ (°C)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{va}$ (cal/mol)	Normal boiling point, $T_B$ (°K)	Critical temperature, $T_C$ (°K)	Organic carbon partition coefficient, $K_{oc}$ (cm <sup>3</sup> /g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF (µg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., R1C (mg/m <sup>3</sup> )
7.20E-02	8.20E-06	1.84E-02	25	8,288	394.40	620.20	1.55E+02	2.00E+02	5.9E-06	3.5E-02

END

## Chemical Properties Sheet for PCE

Former 901/902 Thompson Place  
Sunnyvale, California

By: JC Date: 04/12/11 Project No. OD10160080

**AMEC Geomatrix**

Figure **C-1b**

# INTERMEDIATE CALCULATIONS SHEET

Source-building separation, $L_r$ (cm)	Vadose zone soil air-filled porosity, $\theta_a^v$ (cm <sup>3</sup> /cm <sup>3</sup> )	Vadose zone effective total fluid saturation, $S_w$ (cm <sup>3</sup> /cm <sup>3</sup> )	Vadose zone soil intrinsic permeability, $k_i$ (cm <sup>2</sup> )	Vadose zone soil relative air permeability, $k_g$ (cm <sup>2</sup> )	Vadose zone soil effective vapor permeability, $k_v$ (cm <sup>2</sup> )	Thickness of capillary zone, $L_{cz}$ (cm)	Total porosity in capillary zone, $n_{cz}$ (cm <sup>3</sup> /cm <sup>3</sup> )	Air-filled porosity in capillary zone, $\theta_{a,cz}$ (cm <sup>3</sup> /cm <sup>3</sup> )	Water-filled porosity in capillary zone, $\theta_{w,cz}$ (cm <sup>3</sup> /cm <sup>3</sup> )	Floor-wall seam perimeter, $X_{crack}$ (cm)
--	--	---	---	--	---	--	--	--	--	---

167.88	0.251	#N/A	#N/A	#N/A	1.00E-08	37.50	0.399	0.067	0.332	4,000
--------	-------	------	------	------	----------	-------	-------	-------	-------	-------

Bldg. ventilation rate, $Q_{building}$ (cm <sup>3</sup> /s)	Area of enclosed space below grade, $A_B$ (cm <sup>2</sup> )	Crack-to-total area ratio, $\eta$ (unitless)	Crack depth below grade, $Z_{crack}$ (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,TS}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, $H_{TS}$ (atm-m <sup>3</sup> /mol)	Henry's law constant at ave. groundwater temperature, $H'_{TS}$ (unitless)	Vapor viscosity at ave. soil temperature, $\mu_{TS}$ (g/cm-s)	Vadose zone effective diffusion coefficient, $D_{eff,v}$ (cm <sup>2</sup> /s)	Capillary zone effective diffusion coefficient, $D_{eff,cz}$ (cm <sup>2</sup> /s)	Total overall effective diffusion coefficient, $D_{eff,T}$ (cm <sup>2</sup> /s)
---	--	--	---	---	--	--	---	---	---	---

6.78E+04	1.00E+06	5.00E-03	15	9,421	1.65E-02	6.78E-01	1.79E-04	4.53E-03	5.87E-05	2.51E-04
----------	----------	----------	----	-------	----------	----------	----------	----------	----------	----------

Diffusion path length, $L_d$ (cm)	Convection path length, $L_c$ (cm)	Source vapor conc., $C_{source}$ (ug/m <sup>3</sup> )	Crack radius, $r_{crack}$ (cm)	Average vapor flow rate into bldg., $Q_{soil}$ (cm <sup>3</sup> /s)	Crack effective diffusion coefficient, $D^{crack}$ (cm <sup>2</sup> /s)	Area of crack, $A_{crack}$ (cm <sup>2</sup> )	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, $\alpha$ (unitless)	Infinite source bldg. conc., $C_{building}$ (ug/m <sup>3</sup> )	Unit risk factor, URF (ug/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., RfC (mg/m <sup>3</sup> )
---	--	---	--------------------------------------	---	---	---	---	---	--	--	---

167.88	15	6.78E+02	1.25	8.33E+01	4.53E-03	5.00E+03	9.34E+15	2.17E-05	1.47E-02	5.9E-06	3.5E-02
--------	----	----------	------	----------	----------	----------	----------	----------	----------	---------	---------

Transfer Factor AF

## Intermediate Calculations Sheet for PCE

Former 901/902 Thompson Place  
Sunnyvale, California

By: JC Date: 04/12/11 Project No. OD10160080

**AMEC Geomatrix**

Figure **C-1c**

# DATA ENTRY SHEET

GW-SCREEN  
Version 3.0: 04/03

Reset to  
Defaults

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES ☒ X  
OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION  
(enter "X" in "YES" box and initial groundwater conc. below)

YES ☐

ENTER Chemical CAS No. (numbers only, no dashes)	ENTER Initial groundwater conc., C <sub>gw</sub> (µg/L)	Chemical
79016		Trichloroethylene

MORE  
↓

ENTER Depth below grade to bottom of enclosed space floor, L <sub>f</sub> (cm)	ENTER Depth below grade to water table, L <sub>wt</sub> (cm)	ENTER SCS soil type directly above water table	ENTER Average soil groundwater temperature, T <sub>s</sub> (°C)	ENTER Average vapor flow rate into bldg. (Leave blank to calculate) C <sub>avg</sub> (L/m)
15	152.88	L	23	5

MORE  
↓

ENTER Vadose zone SCS soil type (used to estimate soil vapor permeability)	ENTER User-defined vadose zone soil vapor permeability, k <sub>v</sub> (cm <sup>2</sup> /s)	ENTER Vadose zone SCS soil type  <small>Lookup Soil Parameters</small>	ENTER Vadose zone soil dry bulk density, ρ <sub>d</sub> <sup>1</sup> (g/cm <sup>3</sup> )	ENTER Vadose zone soil total porosity, n <sup>1</sup> (unitless)	ENTER Vadose zone soil water-filled porosity, θ <sub>w</sub> <sup>1</sup> (cm <sup>3</sup> /cm <sup>3</sup> )
	1.00E-08	L	1.59	0.399	0.148

MORE  
↓

ENTER Target risk for carcinogens, TR (unitless)	ENTER Target hazard quotient for noncarcinogens, THQ (unitless)	ENTER Averaging time for carcinogens, AT <sub>c</sub> (yrs)	ENTER Averaging time for noncarcinogens, AT <sub>nc</sub> (yrs)	ENTER Exposure duration, ED (yrs)	ENTER Exposure frequency, EF (days/yr)
1.0E-06	1	70	36	30	350

Used to calculate risk-based  
groundwater concentration.

DTSD  
Vapor Intrusion Guidance  
Interim Final 12/04  
(last modified 2/4/05)

## Transfer Factor Calculation – Input Sheet for TCE

Former 901/902 Thompson Place  
Sunnyvale, California

By: JC Date: 04/12/11 Project No. OD10160080

**AMEC Geomatrix**

Figure **C-2a**

# CHEMICAL PROPERTIES SHEET

Diffusivity in air, $D_a$ (cm <sup>2</sup> /s)	Diffusivity in water, $D_w$ (cm <sup>2</sup> /s)	Henry's law constant at reference temperature, H (atm-m <sup>3</sup> /mol)	Henry's law constant reference temperature, $T_R$ (°C)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, $T_b$ (°K)	Critical temperature, $T_c$ (°K)	Organic carbon partition coefficient, $K_{oc}$ (cm <sup>3</sup> /g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF (µg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., RfC (mg/m <sup>3</sup> )
7.90E-02	9.10E-06	1.03E-02	25	7,505	360.36	544.20	1.66E+02	1.47E+03	2.0E-06	6.0E-01

END

## Chemical Properties Sheet for TCE

Former 901/902 Thompson Place  
Sunnyvale, California

By: JC Date: 04/12/11 Project No. OD10160080

**AMEC Geomatrix**

Figure **C-2b**

INTERMEDIATE CALCULATIONS SHEET

Source-building separation, $L_1$ (cm)	Vadose zone soil air-filled porosity, $\theta_{a,v}$ (cm <sup>3</sup> /cm <sup>3</sup> )	Vadose zone effective total fluid saturation, $S_{e,v}$ (cm <sup>3</sup> /cm <sup>3</sup> )	Vadose zone soil intrinsic permeability, $K$ (cm <sup>2</sup> )	Vadose zone soil relative air permeability, $k_{ra}$ (cm <sup>2</sup> )	Vadose zone effective vapor permeability, $k_v$ (cm <sup>2</sup> )	Thickness of capillary zone, $L_c$ (cm)	Total porosity in capillary zone, $n_c$ (cm <sup>3</sup> /cm <sup>3</sup> )	Air-filled porosity in capillary zone, $\theta_{a,c}$ (cm <sup>3</sup> /cm <sup>3</sup> )	Water-filled porosity in capillary zone, $\theta_{w,c}$ (cm <sup>3</sup> /cm <sup>3</sup> )	Floor-wall seam perimeter, $X_{seam}$ (cm)
167.86	0.251	#N/A	#N/A	#N/A	1.00E-06	67.50	0.399	0.067	0.332	4.000

Bldg. ventilation rate, $Q_{\text{venting}}$ (cm <sup>3</sup> /s)	Area of enclosed space below grade, $A_0$ (cm <sup>2</sup> )	Crack-to-total area ratio, $\eta$ (unitless)	Crack depth below grade, $Z_{\text{crack}}$ (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,Tg}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, $H_{Tg}$ (atm·m <sup>3</sup> /mol)	Henry's law constant at ave. groundwater temperature, $H_{Tg}$ (unitless)	Vapor viscosity at ave. soil temperature, $\mu_{Tg}$ (g/cm·s)	Vadose zone effective diffusion coefficient, $D_{e,v}$ (cm <sup>2</sup> /s)	Capillary zone effective diffusion coefficient, $D_{e,c}$ (cm <sup>2</sup> /s)	Total overall effective diffusion coefficient, $D_{e,t}$ (cm <sup>2</sup> /s)
6.78E-04	1.00E+06	5.00E-03	15	8.395	0.34E-03	3.94E-01	1.79E-04	4.97E-03	6.61E-05	2.83E-04

Diffusion path length, $L_d$ (cm)	Convection path length, $L_c$ (cm)	Source vapor conc., $C_{\text{source}}$ (µg/m <sup>3</sup> )	Crack radius, $r_{\text{crack}}$ (cm)	Average vapor flow rate into bldg., $Q_{\text{avg}}$ (cm <sup>3</sup> /s)	Crack effective diffusion coefficient, $D_{\text{crack}}$ (cm <sup>2</sup> /s)	Area of crack, $A_{\text{crack}}$ (cm <sup>2</sup> )	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, $\alpha$ (unitless)	Infinite source bldg. conc., $C_{\text{bldg}}$ (µg/m <sup>3</sup> )	Unit risk factor, URF (µg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., RfC (mg/m <sup>3</sup> )
167.86	15	3.94E+02	1.25	9.53E+01	4.97E-03	5.00E+00	3.59E+14	2.44E-05	9.26E-03	2.0E-06	6.0E-01

Transfer Factor AF

Intermediate Calculations Sheet for TCE

Former 901/902 Thompson Place  
Sunnyvale, California

By: JC Date: 04/12/11 Project No. OD10160080

AMEC Geomatrix

Figure C-2c



GW-SCREEN  
Version 3.0: 04/03

Reset to  
Defaults

# DATA ENTRY SHEET

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" in "YES" box)

YES ☒ X  
OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION  
(enter "X" in "YES" box and initial groundwater conc. below)

YES ☐

ENTER

Chemical  
CAS No.  
(numbers only,  
no dashes)

ENTER

Initial  
groundwater  
conc.,  
 $C_w$   
( $\mu\text{g/L}$ )

Chemical

158592		oic-1,2-Dichloroethylene
--------	--	--------------------------

ENTER

Depth  
below grade  
to bottom  
of enclosed  
space floor,  
 $L_f$   
(cm)

ENTER

Depth  
below grade  
to water table,  
 $L_w$   
(cm)

ENTER

SCS  
soil type  
directly above  
water table

ENTER

Average  
soil  
groundwater  
temperature,  
 $T_g$   
( $^{\circ}\text{C}$ )

ENTER

Average vapor  
flow rate into bldg.  
(Leave blank to calculate)  
 $Q_{avg}$   
( $\text{L/m}$ )

15	182.88	L	73
----	--------	---	----

5
---

MORE  
↓

ENTER

Vadose zone  
SCS  
soil type  
(used to estimate  
soil vapor  
permeability)

OR

ENTER

User-defined  
vadose zone  
soil vapor  
permeability,  
 $k_p$   
( $\text{cm}^2$ )

ENTER

Vadose zone  
SCS  
soil type  
  
[lookup Soil  
Parameters]

ENTER

Vadose zone  
soil dry  
bulk density,  
 $\rho_b$   
( $\text{g/cm}^3$ )

ENTER

Vadose zone  
soil total  
porosity,  
 $n$   
(unitless)

ENTER

Vadose zone  
soil water-filled  
porosity,  
 $f_{w,f}$   
( $\text{cm}^3/\text{cm}^3$ )

	1.0E-08	L	1.89	0.392	0.148
--	---------	---	------	-------	-------

MORE  
↓

ENTER

Target  
risk for  
carcinogens,  
 $TR$   
(unitless)

ENTER

Target hazard  
quotient for  
noncarcinogens,  
 $THQ$   
(unitless)

ENTER

Averaging  
time for  
carcinogens,  
 $AT_c$   
(yrs)

ENTER

Averaging  
time for  
noncarcinogens,  
 $AT_{nc}$   
(yrs)

ENTER

Exposure  
duration,  
 $ED$   
(yrs)

ENTER

Exposure  
frequency,  
 $EF$   
(days/yr)

1.0E-06	1	70	30	30	350
---------	---	----	----	----	-----

Used to calculate risk-based  
groundwater concentration.

## Transfer Factor Calculation – Input Sheet for cDCE

Former 901/902 Thompson Place  
Sunnyvale, California

By: JC Date: 04/12/11 Project No. OD10160080

AMEC Geomatrix

Figure C-3a

# CHEMICAL PROPERTIES SHEET

Diffusivity in air, $D_a$ (cm <sup>2</sup> /s)	Diffusivity in water, $D_w$ (cm <sup>2</sup> /s)	Henry's law constant at reference temperature, H (atm-m <sup>3</sup> /mol)	Henry's law constant reference temperature, $T_H$ (°C)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, $T_B$ (°K)	Critical temperature, $T_C$ (°K)	Organic carbon partition coefficient, $K_{oc}$ (cm <sup>3</sup> /g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF (µg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., RfC (mg/m <sup>3</sup> )
7.36E-02	1.13E-05	4.07E-03	25	7,192	333.65	544.00	3.55E+01	3.50E+03	0.0E+00	3.5E-02

END

## Chemical Properties Sheet for cDCE

Former 901/902 Thompson Place  
Sunnyvale, California

By: JC Date: 04/12/11 Project No. OD10160080

**AMEC Geomatrix**

Figure **C-3b**

INTERMEDIATE CALCULATIONS SHEET

Source-building separation, $L_s$ (cm)	Vadose zone soil air-filled porosity, $\theta_a^v$ (cm <sup>3</sup> /cm <sup>3</sup> )	Vadose zone effective total fluid saturation, $S_a$ (cm <sup>3</sup> /cm <sup>3</sup> )	Vadose zone soil intrinsic permeability, $k$ (cm <sup>2</sup> )	Vadose zone soil relative air permeability, $k_{ra}$ (cm <sup>2</sup> )	Vadose zone soil effective vapor permeability, $k_v$ (cm <sup>2</sup> )	Thickness of capillary zone, $L_c$ (cm)	Total porosity in capillary zone, $n_c$ (cm <sup>3</sup> /cm <sup>3</sup> )	Air-filled porosity in capillary zone, $\theta_{a,c}$ (cm <sup>3</sup> /cm <sup>3</sup> )	Water-filled porosity in capillary zone, $\theta_{w,c}$ (cm <sup>3</sup> /cm <sup>3</sup> )	Floor-wall seam perimeter, $X_{seam}$ (cm)
167.88	0.251	#NA	#NA	#NA	1.00E-08	37.50	0.399	0.067	0.332	4,500

Bldg. ventilation rate, $Q_{\text{ventg}}$ (cm <sup>3</sup> /s)	Area of enclosed space below grade, $A_g$ (cm <sup>2</sup> )	Crack-to-total area ratio, $\eta$ (unitless)	Crack depth below grade, $Z_{\text{crack}}$ (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,gs}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, $H_{rg}$ (atm-m <sup>3</sup> /mol)	Henry's law constant at ave. groundwater temperature, $H_{rg}$ (unitless)	Vapor viscosity at ave. soil temperature, $\mu_{rg}$ (g/cm-s)	Vadose zone effective diffusion coefficient, $D_{\text{eff}}^v$ (cm <sup>2</sup> /s)	Capillary zone effective diffusion coefficient, $D_{\text{eff}}^c$ (cm <sup>2</sup> /s)	Total overall effective diffusion coefficient, $D_{\text{eff}}^t$ (cm <sup>2</sup> /s)
6.78E+04	1.00E+06	5.00E-03	15	7,602	3.73E-03	1.54E-01	1.79E-04	4.63E-03	6.98E-05	2.97E-04

Diffusion path length, $L_d$ (cm)	Convection path length, $L_c$ (cm)	Source vapor conc., $C_{\text{source}}$ (µg/m <sup>3</sup> )	Crack radius, $r_{\text{crack}}$ (cm)	Average vapor flow rate into bldg., $Q_{\text{air}}$ (cm <sup>3</sup> /s)	Crack effective diffusion coefficient, $D_{\text{eff}}^{\text{crack}}$ (cm <sup>2</sup> /s)	Area of crack, $A_{\text{crack}}$ (cm <sup>2</sup> )	Exponent of equivalent foundation Peclet number, $\exp(Pe^f)$ (unitless)	Infinite source indoor attenuation coefficient, $\alpha$ (unitless)	Infinite source bldg. conc., $C_{\text{source}}$ (µg/m <sup>3</sup> )	Unit risk factor, URF (µg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., RfC (mg/m <sup>3</sup> )
167.88	15	1.54E+02	1.25	8.33E+01	4.83E-09	5.00E+09	4.19E+15	2.95E-05	3.92E+03	NA	0.5E-02

Transfer Factor AF

Intermediate Calculations Sheet for cDCE

Former 901/902 Thompson Place  
Sunnyvale, California

By: JC Date: 04/12/11 Project No. OD10160080

**AMEC Geomatrix**

Figure **C-3c**

GW-SCREEN  
Version 3.0; 04/02

Reset to  
Defaults

# DATA ENTRY SHEET

CALCULATE RISK-BASED GROUNDWATER CONCENTRATION (enter "X" or "YES" box)

YES ☒ X  
OR

CALCULATE INCREMENTAL RISKS FROM ACTUAL GROUNDWATER CONCENTRATION  
(enter "X" or "YES" box and actual groundwater conc. below)

YES ☐

ENTER

Chemical  
CAS No.  
(numbers only,  
no dashes)

ENTER

Initial  
groundwater  
conc.,  
 $C_0$   
(ppb/L)

Chemical

75014	Vinyl chloride monomer
-------	------------------------

ENTER

Depth  
below grade  
to bottom  
of enclosed  
space floor,  
 $L_1$   
(cm)

ENTER

Depth  
below grade  
to water table,  
 $L_w$   
(cm)

ENTER

RCS  
soil type  
(slightly above  
water table)

ENTER

Average  
soil  
groundwater  
temperature,  
 $T_s$   
(°C)

ENTER

Average vapor  
flow rate and flag  
(Leave blank to calculate)

$Q_{avg}$   
(L/min)

15	186.88	L	62
----	--------	---	----

5
---

MORE  
+

MORE  
+

ENTER

Vadose zone  
SCS  
soil type  
used to estimate  
soil vapor  
permeability

OR

ENTER

User-defined  
vadose zone  
soil vapor  
permeability,  
 $k_v$   
(cm<sup>2</sup>/s)

ENTER

Vadose zone  
SCS  
soil type  
(Leave for  
Permeability)

ENTER

Vadose zone  
soil dry  
bulk density,  
 $\rho_b$   
(g/cm<sup>3</sup>)

ENTER

Vadose zone  
soil total  
porosity,  
 $n$   
(unitless)

ENTER

Vadose zone  
soil water filled  
porosity,  
 $n_w$   
(cm<sup>3</sup>/cm<sup>3</sup>)

1.0E-08	L	1.58	0.388	0.188
---------	---	------	-------	-------

MORE  
+

ENTER

Target  
risk for  
carcinogens,  
 $TR$   
(unitless)

ENTER

Target hazard  
quotient for  
noncarcinogens,  
 $HQ$   
(unitless)

ENTER

Averaging  
time for  
carcinogens,  
 $AT_c$   
(yrs)

ENTER

Averaging  
time for  
noncarcinogens,  
 $AT_{nc}$   
(yrs)

ENTER

Exposure  
duration,  
 $ED$   
(yrs)

ENTER

Exposure  
frequency,  
 $EF$   
(days/yr)

1.0E-06	1	70	30	30	350
---------	---	----	----	----	-----

Used to calculate risk-based  
groundwater concentration

## Transfer Factor Calculation – Input Sheet for VC

Former 901/902 Thompson Place  
Sunnyvale, California

By: JC Date: 04/12/11 Project No. OD10160080

AMEC Geomatrix

Figure C-4a

# CHEMICAL PROPERTIES SHEET

Diffusivity in air, $D_a$ (cm <sup>2</sup> /s)	Diffusivity in water, $D_w$ (cm <sup>2</sup> /s)	Henry's law constant at reference temperature, H (atm-m <sup>3</sup> /mol)	Henry's law constant reference temperature, $T_R$ (°C)	Enthalpy of vaporization at the normal boiling point, $\Delta H_{v,b}$ (cal/mol)	Normal boiling point, $T_B$ (°K)	Critical temperature, $T_C$ (°K)	Organic carbon partition coefficient, $K_{oc}$ (cm <sup>3</sup> /g)	Pure component water solubility, S (mg/L)	Unit risk factor, URF (µg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., RfC (mg/m <sup>3</sup> )
1.06E-01	1.23E-05	2.69E-02	25	5,250	259.25	432.00	1.86E+01	8.80E+03	7.8E-05	1.0E-01

END

## Chemical Properties Sheet for VC

Former 901/902 Thompson Place  
Sunnyvale, California

By: JC Date: 04/12/11 Project No. OD10160080

**AMEC Geomatrix**

Figure **C-4b**

INTERMEDIATE CALCULATIONS SHEET

Source-building separation, $L_s$ (cm)	Vadose zone soil air-filled porosity, $\theta_a$ (cm <sup>3</sup> /cm <sup>3</sup> )	Vadose zone effective total fluid saturation, $S_e$ (cm <sup>3</sup> /cm <sup>3</sup> )	Vadose zone soil intrinsic permeability, $k_i$ (cm <sup>2</sup> )	Vadose zone soil relative air permeability, $k_{ra}$ (cm <sup>2</sup> )	Vadose zone soil effective vapor permeability, $k_v$ (cm <sup>2</sup> )	Thickness of capillary zone, $L_{cz}$ (cm)	Total porosity in capillary zone, $\theta_{cz}$ (cm <sup>3</sup> /cm <sup>3</sup> )	Air-filled porosity in capillary zone, $\theta_{a,cz}$ (cm <sup>3</sup> /cm <sup>3</sup> )	Water-filled porosity in capillary zone, $\theta_{w,cz}$ (cm <sup>3</sup> /cm <sup>3</sup> )	Floor-wall seam perimeter, $X_{seam}$ (cm)
167.88	0.251	#N/A	#N/A	#N/A	1.00E-08	37.50	0.399	0.067	0.332	4,000

Bldg. ventilation rate, $Q_{\text{building}}$ (cm <sup>3</sup> /s)	Area of enclosed space below grade, $A_g$ (cm <sup>2</sup> )	Crack-to-total area ratio, $\eta$ (unitless)	Crack depth below grade, $Z_{\text{crack}}$ (cm)	Enthalpy of vaporization at ave. groundwater temperature, $\Delta H_{v,Tg}$ (cal/mol)	Henry's law constant at ave. groundwater temperature, $H_{Tg}$ (atm·m <sup>3</sup> /mol)	Henry's law constant at ave. groundwater temperature, $H_{Tg}$ (unitless)	Vapor viscosity at ave. soil temperature, $\mu_{Ts}$ (g/cm·s)	Vadose zone effective diffusion coefficient, $D_{vz}^{eff}$ (cm <sup>2</sup> /s)	Capillary zone effective diffusion coefficient, $D_{cz}^{eff}$ (cm <sup>2</sup> /s)	Total overall effective diffusion coefficient, $D^{eff}$ (cm <sup>2</sup> /s)
6.78E+04	1.00E+06	5.00E-03	15	4,852	2.55E-02	1.95E+00	1.79E-04	6.67E-03	8.55E-05	3.88E-04

Diffusion path length, $L_d$ (cm)	Convection path length, $L_c$ (cm)	Source vapor conc., $C_{\text{source}}$ (μg/m <sup>3</sup> )	Crack radius, $r_{\text{crack}}$ (cm)	Average vapor flow rate into bldg., $Q_{\text{avg}}$ (cm <sup>3</sup> /s)	Crack effective diffusion coefficient, $D^{crack}$ (cm <sup>2</sup> /s)	Area of crack, $A_{\text{crack}}$ (cm <sup>2</sup> )	Exponent of equivalent foundation Peclet number, $\exp(Pe)$ (unitless)	Infinite source indoor attenuation coefficient, $\alpha$ (unitless)	Infinite source bldg. conc., $C_{\text{building}}$ (μg/m <sup>3</sup> )	Unit risk factor, URF (μg/m <sup>3</sup> ) <sup>-1</sup>	Reference conc., R/C (mg/m <sup>3</sup> )
167.88	15	1.05E+03	1.25	8.33E+01	6.67E-03	5.90E+03	7.05E+10	3.14E-05	3.29E-02	7.8E-05	1.0E+01

Transfer Factor AF

Intermediate Calculations Sheet for VC

Former 901/902 Thompson Place  
Sunnyvale, California

By: JC Date: 04/12/11 Project No. OD10160080

AMEC Geomatrix

Figure C-4c

---

**APPENDIX D**

Remediation Time-Frame Analysis

## TABLE OF CONTENTS

	Page
1.0 INTRODUCTION.....	1
2.0 CONCEPTUAL MODEL FOR REMEDIATION TIME-FRAME ANALYSIS .....	1
3.0 MODEL SETUP .....	2
3.1 MODEL DOMAIN AND GRID .....	2
3.2 MODELING CODES AND SOLVER SETTINGS FOR FLOW SIMULATIONS .....	3
3.3 MODELING CODES AND SOLVER SETTINGS FOR TRANSPORT SIMULATIONS .....	3
3.4 AQUIFER HYDRAULIC PROPERTIES .....	3
3.5 CHEMICAL AND TRANSPORT PROPERTIES .....	3
3.6 BOUNDARY CONDITIONS USED FOR MODFLOW AND MT3D .....	4
3.7 CONCENTRATION MONITORING POINTS .....	4
4.0 SIMULATION SCENARIOS .....	4
4.1 BASE MODEL: CONSTANT CONTAMINATION FROM SOURCE .....	4
4.2 SCENARIO 1: SOURCE REMEDIATED .....	5
4.3 SCENARIO 2: SOURCE AND TRANSMISSIVE ZONE REMEDIATED .....	5
4.4 SCENARIOS 3, 4, AND 5: REMEDIATION OF THE LOW PERMEABILITY ZONE.....	5
4.5 SENSITIVITY ANALYSIS: CASE 1 .....	5
4.6 SENSITIVITY ANALYSIS: CASE 2 .....	6
4.7 SENSITIVITY ANALYSIS: CASE 3 .....	6
5.0 RESULTS .....	6
5.1 BASE MODEL .....	6
5.2 CONCENTRATION TRENDS FOR SCENARIOS 1 THROUGH 5.....	6
5.2.1 Scenario 1.....	6
5.2.3 Scenario 2.....	7
5.2.4 Scenarios 3, 4, and 5 .....	7
5.3 SENSITIVITY ANALYSIS.....	8
5.3.1 Sensitivity Case 1 .....	8
5.3.2 Sensitivity Case 2 .....	8
5.3.3 Sensitivity Case 3 .....	8
6.0 DISCUSSION.....	8
7.0 REFERENCES .....	10

## TABLES

Table D-1	Aquifer Properties Used in Groundwater Model
Table D-2	Solute Transport Parameters Used for Transport Simulation

## FIGURES

Figure D-1	Model Domain and Locations of Boundary Condition Cells
Figure D-2	Concentration Trends at Various Monitoring Points—Base Model Simulation
Figure D-3	Concentration Trends at Monitoring Point MP60
Figure D-4	Concentration Trends at Monitoring Point MP80



## TABLE OF CONTENTS

(Continued)

Figure D-5	Concentration Trends at Monitoring Point MP100
Figure D-6	Concentration Trends at Monitoring Point MP120
Figure D-7	Concentration Trends at Monitoring Point MP140
Figure D-8	Sensitivity Analysis—Concentration Trends at MP80

## APPENDIX D

### REMEDATION TIME-FRAME ANALYSIS

Former 901/902 Thompson Place  
Sunnyvale, California

#### 1.0 INTRODUCTION

An ideal remedy for site cleanup must be able to achieve cleanup standards within a reasonable time frame and at a reasonable cost. This means that the estimation of remediation time frames (RTFs) is an important step for a remedial alternative (RA) evaluation. Estimated RTFs for individual RAs also form a basis for estimating monetary values of the operation and maintenance of related process options. RTF is a quantity that strongly depends on transport behavior of site-related constituents of concern (COCs) in the aquifer system, and thus chemical transport modeling is often required to facilitate a quantitative or qualitative RTF analysis.

For a highly heterogeneous aquifer system similar to the one beneath the former 901/902 Thompson Place site (the “site”), estimation of actual (absolute) RTF values is difficult because solute transport is often controlled by a slow diffusion-like mass transfer process and the extent and sizes of the low-permeability zones and other heterogeneous aquifer properties are not well characterized. In such circumstances, RTF estimation needs to rely on a site conceptual model focused on the major controlling processes, and thus the estimated RTF values, while not predictive in an absolute sense, are suitable for a comparative evaluation.

The RTF analysis presented in this appendix is based on an abstract conceptual model presented in Section 2. Section 3 provides the setup of numerical modeling and parameters used for simulations. Section 4 describes the simulation scenarios. Section 5 presents the modeling results. Section 6 discusses how the results relate to the RA evaluated in this Focused Feasibility Study.

#### 2.0 CONCEPTUAL MODEL FOR REMEDIATION TIME-FRAME ANALYSIS

It has been demonstrated in both laboratory and field studies that the extent of aquifer heterogeneity can significantly affect RTFs (Air Force Center for Environmental Excellence, 2007; Sale et al., 2008). Low-permeability zones in an aquifer system have been shown to affect plume evolution in two significant ways:

- Initially, COCs in the transmissive zones are attenuated due to diffusion into the low-permeability zones.
- After the COC sources in the transmissive zones are depleted, the low-permeability zone can act as a source to transfer COCs back to the transmissive zones.

In the Final Feasibility Study approved in 1991 for the site, a set of estimated RTFs was presented (Harding Lawson Associates [HLA], 1991). These estimates were based on a batch flushing model, which did not consider the effects of aquifer heterogeneity and mass transfer between the transmissive and low-permeability zones. The estimated RTFs for reaching the TCE cleanup goal in the A zone and B zone aquifer were 18 years and 9 years, respectively. These estimated RTFs are proven to be overly optimistic since TCE concentrations at many monitoring wells in 2005 were significantly higher than the cleanup goal of 5 micrograms per liter ( $\mu\text{g/L}$ ). Thus it is not clear whether the groundwater extraction and treatment (GWET) system at the site can achieve site cleanup goals in a reasonable time frame (Water Board, 2009). According to the historical operation data for the GWET system, the COC mass removal efficiency declined over time, and reached an asymptotic level after 1995 (U.S. EPA, 1996), indicating that back-diffusion of COCs from the low-permeability zones controlled the transport of COC mass to the extraction wells.

This historical data highlights the need for incorporating the process of mass transfer between the transmissive and low-permeability zones in order to improve RTF estimates. The improved site conceptual model for the RTF analysis assumes the following: (1) solutes in groundwater can be transferred between the transmissive and low-permeability zones through diffusion and transverse dispersion, (2) horizontal groundwater flow occurs in both types of zones, and (3) COC mass stored in the low-permeability zones at the site primarily results from persistent high COC concentrations in the transmissive zones.

The actual site conditions are more complicated than the assumptions listed above. For example, mass transfer limitations are probably also present between localized mobile and immobile lenses within individual types of zones.

### **3.0 MODEL SETUP**

#### **3.1 MODEL DOMAIN AND GRID**

The model domain represents an abstract vertical slice of a portion of the aquifer system. The model domain consists of two hydraulic zones (the transmissive zone and the low-permeability zone), and is 1,600 centimeters (cm) (or 52.5 feet) long and 250 cm (or 8.2 feet) thick. The model domain length is the approximate distance from the DW-1 well to the DW-7 well. The top zone is a transmissive sandy layer (100 cm or 3.3 feet), and the bottom zone represents a low-conductivity silt/clayey layer (150 cm or 4.9 feet). The domain is discretized into 802 columns wide and 250 rows long. The grid is assumed to be oriented in the direction coinciding with that of average groundwater flow in the vicinity of the site.

The transmissive and low-permeability zones are represented in the model as zones 1 and 2, respectively. The contrast between these two hydraulic conductivity zones helps conceptually simulate horizontal and vertical solute transport in a heterogeneous aquifer containing abrupt

contacts between two zones. The graphic presentation of the model domain is provided on Figure D-1.

### **3.2 MODELING CODES AND SOLVER SETTINGS FOR FLOW SIMULATIONS**

MODFLOW 2000, developed by the U.S. Geological Survey, was selected for flow simulation. The PCG2 solver was used to solve the system of flow equations. Groundwater Vistas Version 5.51 was used to process model input and output files. The head change criterion was set to be 0.001 foot, and the residual convergence criterion was set to 1E-8.

### **3.3 MODELING CODES AND SOLVER SETTINGS FOR TRANSPORT SIMULATIONS**

MT3DMS, developed by the U.S. Environmental Protection Agency, was selected for transport simulation. The general conjugate gradient (GCG) solver with the modified Choleski solver option was used to solve the system of transport equations. Groundwater Vistas Version 5.51 was used to process model input and output files. The concentration change convergence criterion was set to 1E-4. The initial time step size was 0.001 day and the time step multiplier was set to be 1.3.

### **3.4 AQUIFER HYDRAULIC PROPERTIES**

The values of aquifer property used in the model are provided in Table D-1. These values were based on the range of values reported in investigation studies from nearby sites (ENVIRON International Group [ENVIRON], 2008; HLA, 1991; The Source Group [Source Group], 2003). The values of hydraulic conductivity for the transmissive and low-conductivity zones in the model are 500 centimeters per day (cm/d) and 10 cm/d, respectively. The anisotropic ratio of horizontal to vertical hydraulic conductivity values is 10. These properties are summarized in Table D-1.

### **3.5 CHEMICAL AND TRANSPORT PROPERTIES**

The values of chemical properties used in the model are based on the chemical properties of trichloroethene, which serves as a representative COC for this analysis. Organic carbon partition coefficient ( $K_{oc}$ ) is 137 liters per kilogram (L/kg) and organic carbon fraction ( $f_{oc}$ ) is 0.20 percent (Source Group, 2003). The effective porosity is 0.20 for the low-permeability zone (1991) and 0.30 for the transmissive zone (Source Group, 2003). Bulk density for the transmissive zone is 1.9 kilograms per liter (kg/L) and that for the low-permeability zone is 1.48 kg/L. The longitudinal and transverse dispersivity values are 4 cm and 1.6 cm, respectively. The small values were used to describe the pore-scale dispersion process (Benekos et al., 2006), necessary for simulating the localized mass transfer process between the transmissive and low-permeability zones. These properties are summarized in Table D-2.

### 3.6 BOUNDARY CONDITIONS USED FOR MODFLOW AND MT3D

Constant head boundary conditions were specified at the left and right sides of the domain boundaries to create a hydraulic gradient of 0.008 (12.8 cm /16,000 cm), which is consistent with the magnitude of observed regional gradients. The constant head specified at the right-side boundary is 12.8 cm, and the constant head specified at the left-side boundary is 0 cm. Concentration boundary conditions vary with simulation scenarios and are described in the following section.

### 3.7 CONCENTRATION MONITORING POINTS

Five “hypothetical monitoring points” were incorporated into the model at the right boundary of the domain to monitor the concentration at various modeling scenarios. These monitoring points are numbered MP60 to MP140 and are placed at a vertical distance of 20 cm from one another, starting 60 cm below the top of the model domain (Figure D-1). The representative monitoring point for the transmissive zone is assumed to be at MP80. The interface monitoring point is at MP100. The representative monitoring point for the low-permeability zone is MP140.

## 4.0 SIMULATION SCENARIOS

Two sets of modeling scenarios were considered. To generate a suitable distribution of initial concentrations in the model domain, the transport of the COC was modeled assuming the source constantly emitted the COC in the transmissive zone from the right-side boundary for 20 years. The resulting concentration distribution was used to construct the initial concentration distributions for the five scenarios described below, in which the COC source was no longer present, and the impact of residual concentrations in the model domain was modeled over a period of 40 years.

A second set of simulations was performed to test the sensitivity of the model by varying certain parameters in a stepwise manner. Each of these modeling scenarios is described below.

### 4.1 BASE MODEL: CONSTANT CONTAMINATION FROM SOURCE

The source was considered to be an area in the left of the domain in the transmissive zone measuring approximately 100 cm in height and 20 cm in width. It was assumed that the source emits 1,000 µg/L of the COC into the transmissive zone for 20 years. The initial COC concentrations in the domain was assumed to be 0.001 µg/L. The COC concentration trend over the entire 20-year period and final COC distribution throughout the entire domain at the end of the 20-year period were observed and documented. The final concentrations were the basis for the initial concentrations for modeling the other scenarios.

#### 4.2 SCENARIO 1: SOURCE REMEDIATED

In this scenario, it was assumed that the COC source has been remediated instantaneously 20 years after the release started. The source concentration at the left-side boundary was set to 0.1  $\mu\text{g/L}$ , and the final domain concentrations from the base model were directly used as the initial COC concentrations. The concentration evolution was modeled for 40 years, and the time taken for concentration to reach the cleanup goal (5  $\mu\text{g/L}$ ) was documented. The concentration evolution in the domain and at the hypothetical monitoring points was also simulated.

#### 4.3 SCENARIO 2: SOURCE AND TRANSMISSIVE ZONE REMEDIATED

In this scenario, it was assumed that both the COC source and the transmissive zone have been remediated after 20 years of the source emission. The source concentration in this scenario was set to 0.1  $\mu\text{g/L}$ , the concentrations in the transmissive zone were also set to 0.1  $\mu\text{g/L}$ , and the initial COC concentrations in the rest of the domain were set to be the same as the final domain concentrations from the base model. The COC evolution was modeled for 40 years, and the time taken for concentration to reach the cleanup goal in the domain and at the hypothetical monitoring points was also simulated.

#### 4.4 SCENARIOS 3, 4, AND 5: REMEDIATION OF THE LOW PERMEABILITY ZONE

In Scenario 3 it was assumed that the COC source and the transmissive zone have been remediated after 20 years of the initial COC release. In addition, the top 10 cm of the low-permeability zone have also been remediated. The source concentration in this scenario was set to 0.1  $\mu\text{g/L}$ , the concentrations in the transmissive zone and the top 10 centimeters of the low-permeability zone were also set to 0.1  $\mu\text{g/L}$ , and the initial concentrations in the rest of the domain were set to be the same as the final domain concentrations from the base model. The COC concentration was modeled for 40 years, and the time taken for concentration to reach the remedial objective was documented. The concentration evolution in the domain and at the monitoring wells was also monitored.

Scenario 4 is the same as Scenario 3 except that the top 20 cm of the low-permeability zone were assumed to be remediated. Scenario 5 is the same as Scenario 3 except that the top 30 cm of the low-permeability zone were assumed to be remediated.

#### 4.5 SENSITIVITY ANALYSIS: CASE 1

The thickness of the remediated area (area with contamination concentration = 0.1  $\mu\text{g/L}$ ) was increased to 50 cm from 30 cm as described in Scenario 5. This simulation was run to determine the depth of the low-permeability zone required to be remediated in order to decrease the extent of the COC concentration rebound at the hypothetical monitoring point MP80. All other conditions were the same as in Scenario 5.

#### 4.6 SENSITIVITY ANALYSIS: CASE 2

It is well known that hydraulic gradient across the domain is a dominant factor in COC transport. The effect of a 25 percent increase in the hydraulic gradient was modeled across the model domain. The effects of this increase were observed and are reported below. All other conditions were the same as Scenario 1, and the results were compared to that scenario.

#### 4.7 SENSITIVITY ANALYSIS: CASE 3

Transverse dispersivity affects the rate of COC transfer between the transmissive and low-permeability zones. A 100 percent increase in the transverse dispersivity was modeled across the model domain to evaluate its effects on the RTF. All other conditions were the same as Scenario 1, and the results were compared to that scenario.

### 5.0 RESULTS

The results of concentration trends at the monitoring points are described below. The cleanup goal for the modeled COC is assumed to be 5 µg/L.

#### 5.1 BASE MODEL

The concentration evolution was observed at five locations (monitoring wells MP60, MP80, MP100, MP120, and MP140) across the thickness of the domain (Figure D-2). These wells are located at the right boundary of the domain at a distance of 60, 80, 100, 120, and 140 cm, respectively, from the top of the domain. It was observed that the final COC concentrations at the three monitoring points in the transmissive zone are between 960 and 980 µg/L, which resemble the source concentration. This demonstrates that the COC from the source has been effectively transmitted across the transmissive zone.

COC concentrations in the lower-permeability zone are less pronounced, as can be seen from Figure D-2. The COC concentrations in the monitoring point farthest from the interface of the zones (MP140) is approximately 100 µg/L at the end of the 2-year time period, and the final simulated concentration at this location reaches a maximum of 620 µg/L at the end of the 20-year simulation period. This result shows that the low-permeability zone absorbs COC mass when the strength of the source in the transmissive zone remains strong.

#### 5.2 CONCENTRATION TRENDS FOR SCENARIOS 1 THROUGH 5

The concentration trends at various monitoring points for Scenarios 1 through 5 are shown on Figures D-3 through D-7.

##### 5.2.1 Scenario 1

The effects of source remediation can be seen in the modeling results for Scenario 1. Since the source was reduced to 0.1 µg/L at the beginning of the simulation, the COC concentrations

in the transmissive zone, although high (approximately 974  $\mu\text{g/L}$ ) at the end of the first quarter year, diminished to 100  $\mu\text{g/L}$  at the end of 1.5 years (548 days), and the concentration at the end of the 40 year (14,600 days) simulation period was approximately 0.1  $\mu\text{g/L}$ . A similar trend was observed in other wells in the transmissive zone (Figures D-3 and D-4), and at the interface of the transmissive zone (Figure D-5), and the low-permeability zone (Figures D-3 and D-4). The time required to cleanup up the aquifer system to its original state (0.001  $\mu\text{g/L}$ ) is expected to be much longer than 40 years, much longer than the time during which the aquifer system was subject to a constant COC loading (20 years).

The effects of source remediation are less pronounced in the low-permeability zone (Figures D-6 and D-7). The final concentration at well MP120 (Figure D-6), which is closest to the interface, diminished to 100 ppb at the end of 13 years (4,745 days), showing that cleanup in the transmissive zone was much faster than that in the low-permeability zone.

### 5.2.3 Scenario 2

The effect of source and transmissive zone remediation can be seen in the modeling results from this scenario. At representative locations in the transmissive zone (MP80), low concentrations were observed after nearly three months (90 days), after which the concentrations increased sharply due to diffusion from the high concentrations in the low-permeability zone and then decrease (Figure D-4). The concentrations reached 10  $\mu\text{g/L}$  by 7 years (2,600 days), and 1  $\mu\text{g/L}$  by 22 years (8,000 days).

At MP100, the time taken to reach 10  $\mu\text{g/L}$  required 13 years (4,750 days), significantly longer than the trend observed at MP80 (Figures D-4 and D-5); concentration diminished to 1  $\mu\text{g/L}$  at the end of 29 years (10,500 days). This is attributed to the fact that MP100 is right at the interface between two zones where it would be subject to more influence from the higher concentrations in the low-permeability zone. The transmissive zone remediation only slightly reduced the time to meet the cleanup goal of 5  $\mu\text{g/L}$  at the monitoring points (Figures D-3 through D-7).

### 5.2.4 Scenarios 3, 4, and 5

These three scenarios evaluate the effects of the low-permeability zone remediation on concentration trends and the time to meet the cleanup goal. Figures D-3 through D-5 show that remediation of a portion of the low-permeability zone can reduce the peak of concentration rebound at the monitoring points in the transmissive zone. The deeper the low-permeability zone is remediated, the smaller the concentration rebound. In general, it was found that every 10 cm increase in thickness of the clean low-permeability zone led to a reduction in the peak concentration at MP80 by nearly 55 percent for the modeled aquifer system. In addition, the trends of the COC concentration reduction at MP60 and MP80 were



faster with an increase in depth of the clean low-permeability zone. These results signify the importance of remediation occurring in the low-permeability zone.

### **5.3 SENSITIVITY ANALYSIS**

#### **5.3.1 Sensitivity Case 1**

The effects observed at monitoring point MP80 of increasing the thickness of the remediated low-permeability zone to 50 cm are provided on Figure D-8. It was found that because of additional cleanup in the low-permeability zone, COC concentrations at well M80 were significantly lower than those for Scenarios 1 through 5 (Figure D-8). The highest concentration reached was 5.7 µg/L at the end of 4 years (1,460 days). Concentrations decreased thereafter, with 1 µg/L observed at the end of 17 years (6,200 days).

#### **5.3.2 Sensitivity Case 2**

When the hydraulic gradient was increased to 0.01 from the existing 0.008, it was found that concentration decrease at MP80 occurred faster after 2,000 days than in Scenario 1 when the head gradient was 0.008. The results indicate that increasing the hydraulic gradient by approximately 20 percent would not significantly reduce the concentrations in the transmissive zone in early time.

#### **5.3.3 Sensitivity Case 3**

In this case, transverse dispersivity was increased by 100 percent to monitor the concentration trend at MP80 in the transmissive zone. It was found that the concentration trend was very similar to that of Scenario 1. The concentration distributions in the model domain over time revealed that an increase in transverse dispersivity accelerated the mass transfer of COC into and out of the low-permeability zone. However, the net effects of the enhanced mass transfer process did not reduce the time to reach the cleanup goal, partly because more COC mass was stored in the low-permeability zone, with increased transverse dispersivity when the source was not remediated.

## **6.0 DISCUSSION**

The simulation results indicate that, for an aquifer system where the COC mass stored in the low-permeability zones sustains the COC concentrations observed in the transmissive zones, the ability of a remedial technology to remediate the low-permeability zones is likely to control the RTF of that technology. Technologies that do not promote in situ destruction of COCs in the low-permeability zone, such as hydraulic containment and permeable reactive barrier, are expected to provide marginal benefits for accelerating site cleanup. In contrast, technologies such as in situ bioremediation (ISB) may significantly reduce the RTF because such technologies can promote reactions in low-permeability zones and within the high permeability zones themselves as discussed below (this process was not simulated herein but would be

expected to yield lower RTFs if biological reduction were to be sustained within the transmissive zone due to an excess of stationary organic carbon).

When anaerobic ISB is used, soluble organic substrate or slow-releasing organic emulsion can be added to the transmissive zones to stimulate necessary reactions in situ. Biodegradation in the transmissive zones helps maintain low COC concentrations therein, and facilitate COC desorption from the low-permeability zones. If the substrate level in the transmissive zones can be maintained for a long time, diffusion of substrate into the low-permeability zones could further help remediate the low-permeability zones. The time required for a small substrate such as hydrogen (a common fermentation product of organic substrate that stimulates chlorinated ethene degradation) to penetrate 65 cm into the low-permeability zones can be estimated using the simple formula below:

$$T = \frac{L^2}{D}$$

where  $T$  is the time frame for diffusion;  $L$  is the representative penetration depth of hydrogen into the low-permeability zones (65 cm); and  $D$  is the diffusion coefficient of hydrogen in an aquifer environment, assumed to be  $2 \times 10^{-5}$  cm/s.

Using the formula, the time to reach a penetration depth of 65 cm is estimated to be 6.7 years. A period of 7 years is thus used to estimate the cost for ISB in this Focused Feasibility Study. Beside hydrogen, fermentation of injected substrate also will produce a large amount of small organic acid molecules, which would also diffuse into the low-permeability zones to support biodegradation. It is noted that the estimate does not consider additional penetration that could be achieved through pumping and substrate injection management. Such enhancement was realized during the ISB implementation at the site; that is, there was no obvious concentration rebound at the substrate injection wells DW-1 and DW-2. Another advantage of using in situ biological or chemical reactions for RTF reduction is that reactions can also help desorption of chemicals from the water immobile zones within either the transmissive or low-permeability portions of the aquifer.

Besides the low-permeability zones, the immobile zones also provide COC mass storage in the aquifer that could sustain the concentration tailing commonly observed at sites remediated using the pump-and-treat approach. In addition, for technologies relying on desorption of COCs from the low-permeability zones, it is difficult to determine when the impact of COCs from offsite, upgradient sources will interfere with and ultimately prevent attainment of cleanup goals in groundwater beneath the site. Therefore, to estimate the cost for the Focused Feasibility Study, the RTF for the technologies relying on slow COC desorption from the low-permeability (e.g., pump-and-treat, monitored natural attenuation, and passive reactive barrier) is set to be 30 years.

In summary, an analysis of RTF has been presented. The RTFs for technologies that do not promote in situ reactions are expected to take a much longer time in comparison with the RTFs for technologies that promote in situ reactions. The extent of RTF reduction depends on the extent of in situ reactions promoted in the low-permeability zones.

## 7.0 REFERENCES

- Air Force Center for Environmental Excellence (AFCEE), 2007, AFCEE Source Zone Initiative, Final Report, May.
- Benekos, I.D., Cirpka, O.A., and Kitanidis, P.K., 2006, Experimental determination of transverse dispersivity in a helix and a cochlea: Water Resources Research, v. 42, W07406, doi:10.1029/2005WR004712.
- California Regional Water Quality Control Board, San Francisco Bay Region (Water Board), 2009, Third Five-Year Review for the Advanced Micro Devices – 901/902 Thompson Place Superfund Site, Sunnyvale, California, September.
- ENVIRON International Corporation, 2008, Chloroform Mass Estimates and Projected Future Groundwater Conditions, Chloroform Release Area at Former Building 028J, Hitachi Global Storage Technologies, Inc., August.
- Harding Lawson Associates (HLA), 1991, Final Feasibility Study for the Companies, Sunnyvale, California, March.
- Sale, T., Newell, C., Stroo, H., Hinchee, R., and Johnson, P., 2008, Frequently Asked Questions Regarding Management of Chlorinated Solvents in Soils and Groundwater, Developed for the Environmental Security Technology Certification Program (ESTCP): <http://www.serdp.org/content/download/8190/100865/version/1/file/FAQ-ChlorinatedSolvents-ER-200530.pdf>, July.
- The Source Group, 2003, Transmittal Letter for Groundwater Flow and Contaminant Transport Modeling Report, Mohawk Laboratories, April.
- United States Environmental Protection Agency (U.S. EPA), 1999, Five-Year Review for the Advanced Micro Devices (AMD) 910 Superfund Site, Sunnyvale, California, September.

**TABLES**

---

**TABLE D-1**

**AQUIFER HYDRAULIC PROPERTY USED IN THE GROUNDWATER MODEL**

Former 901/902 Thompson Place  
Sunnyvale, California

Model Zone	Hydrostratigraphic Unit	Horizontal Hydraulic Conductivity	Vertical Hydraulic Conductivity
		(centimeters per day)	
1	Transmissive Zone	500	50
2	Low-Permeability Zone	10	1

Note

The representative values in this table are based on the following sources: Table 3 of this report; ENVIRON (2008); and Source Group (2003).

**TABLE D-2**

**SOLUTE TRANSPORT PARAMETERS USED FOR TRANSPORT SIMULATION**

Former 901/902 Thompson Place  
Sunnyvale, California

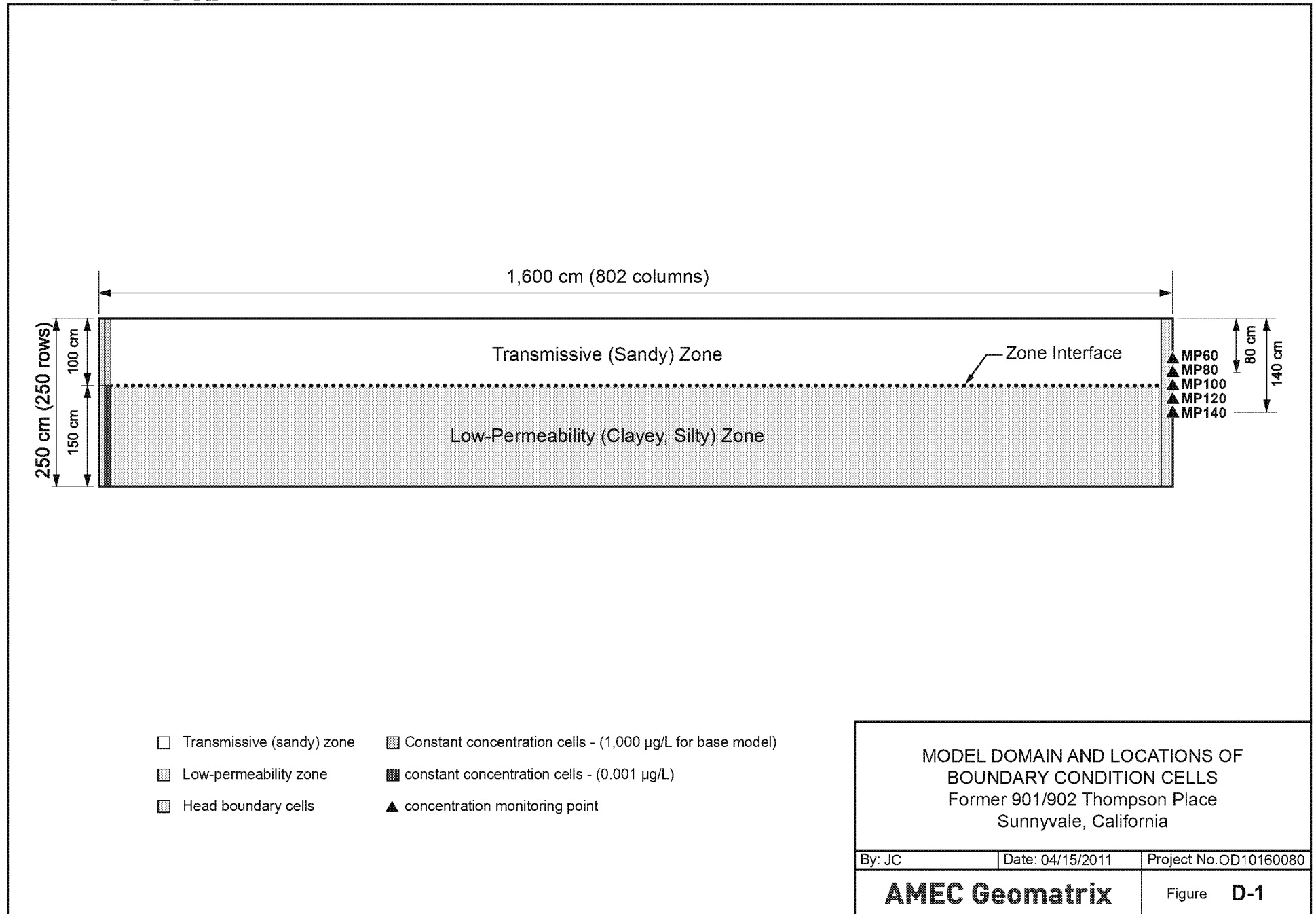
Chemical Property for TCE	Value		Reference
Organic Carbon Partition Coefficient—Koc (L/kg)	137		Source Group (2003)
Aquifer Transport Parameter	TZ	LPL	Reference
Organic Carbon Fraction (foc)	0.20%	0.20%	Source Group (2003)
Bulk Density (kg/L)	1.9	1.48	
Effective Porosity	0.3	0.2	
Longitudinal Dispersivity (cm)	4	4	Benekos et al. (2006)
Transverse (or Vertical) Dispersivity (cm)	1.6	1.6	

Abbreviations

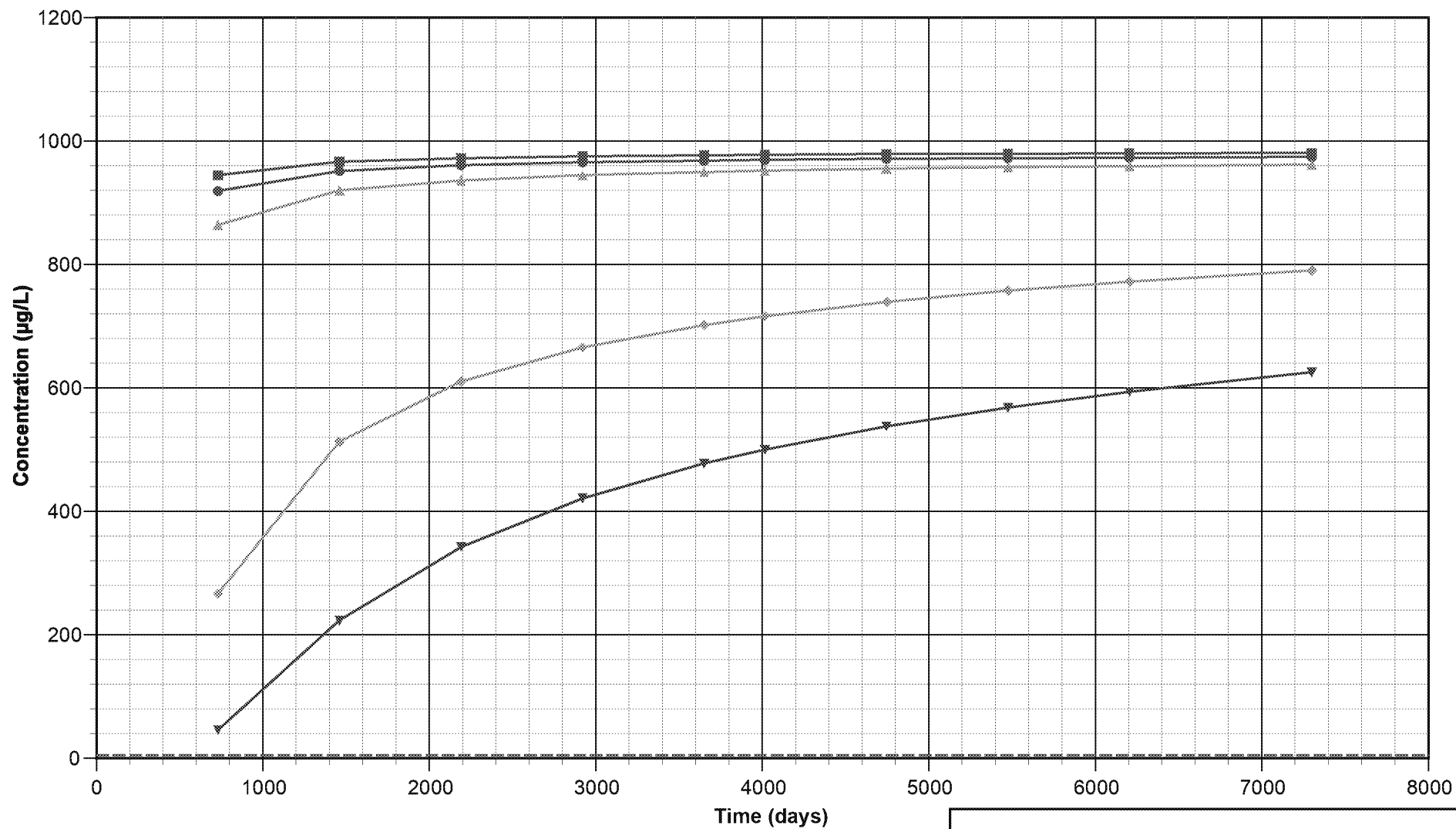
cm = centimeters  
foc = fraction of organic carbon in soil  
kg/L = kilogram per liter  
L/kg = liters per kilogram  
LPZ = low-permeability zone (fine-grained portion of the aquifer)  
TZ = transmissive zone (coarse-grained portion of the aquifer)

---

**FIGURES**







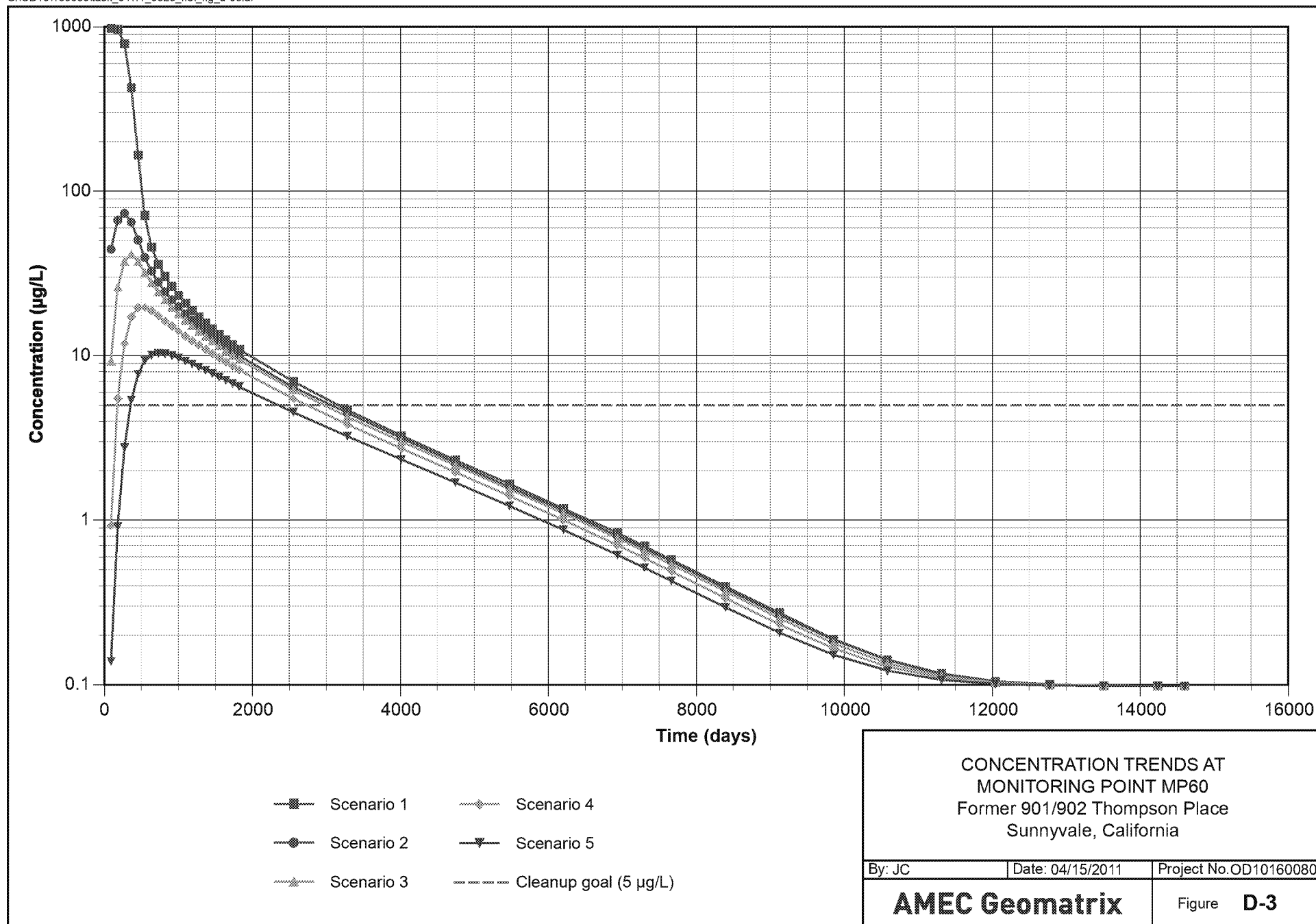
CONCENTRATION TRENDS AT VARIOUS  
MONITORING POINTS BASE MODEL SIMULATION  
Former 901/902 Thompson Place  
Sunnyvale, California

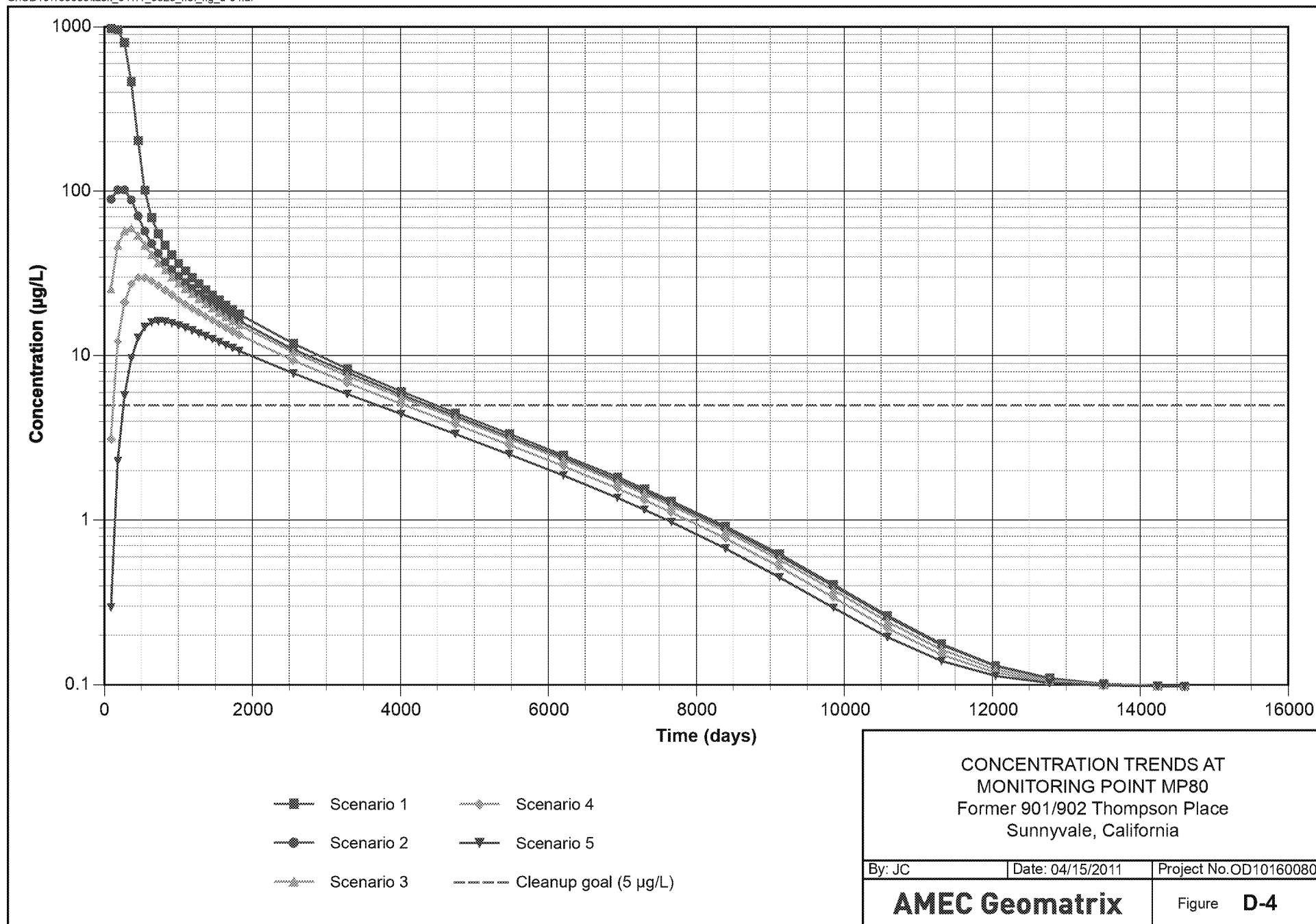
By: JC

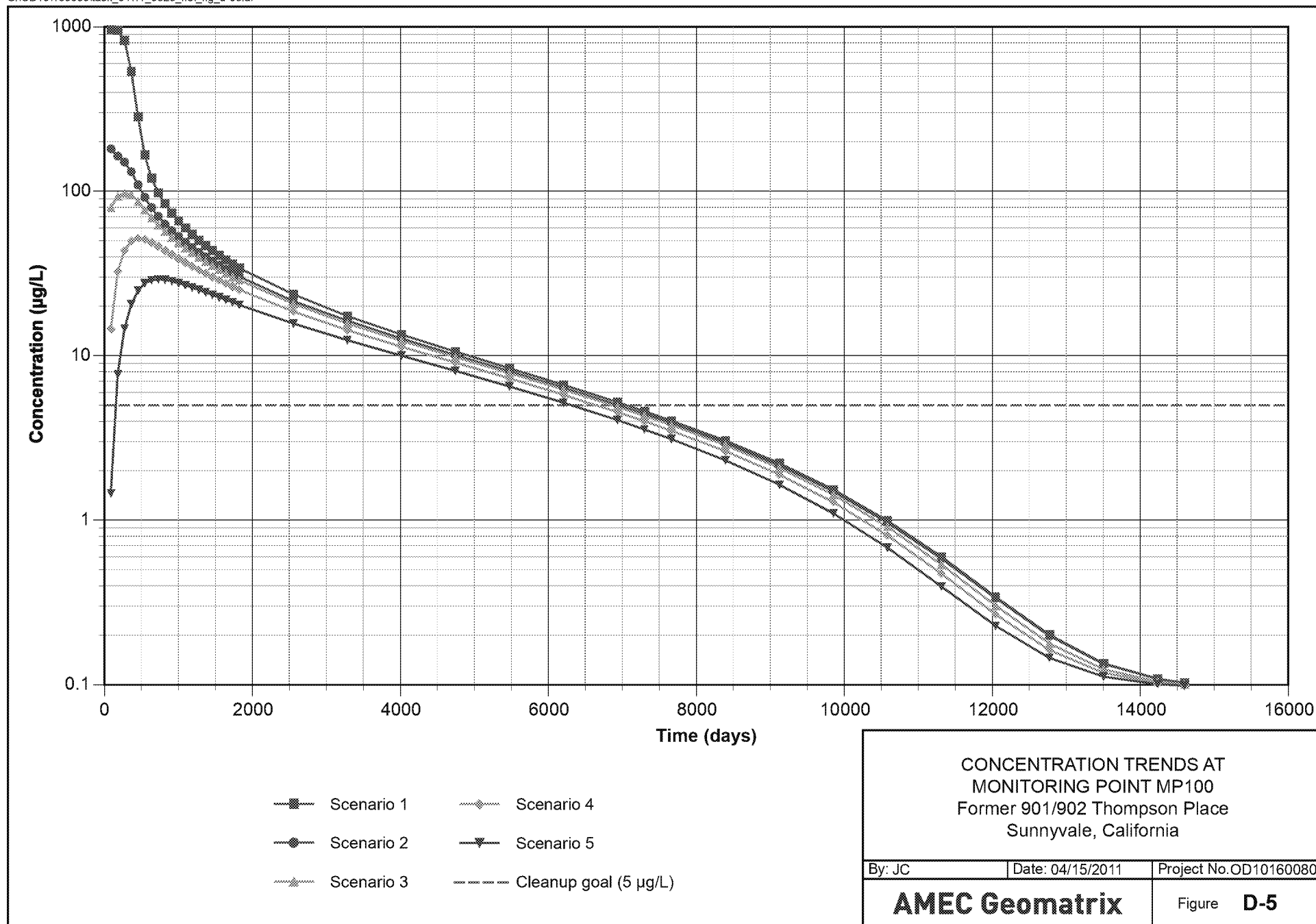
Date: 04/15/2011

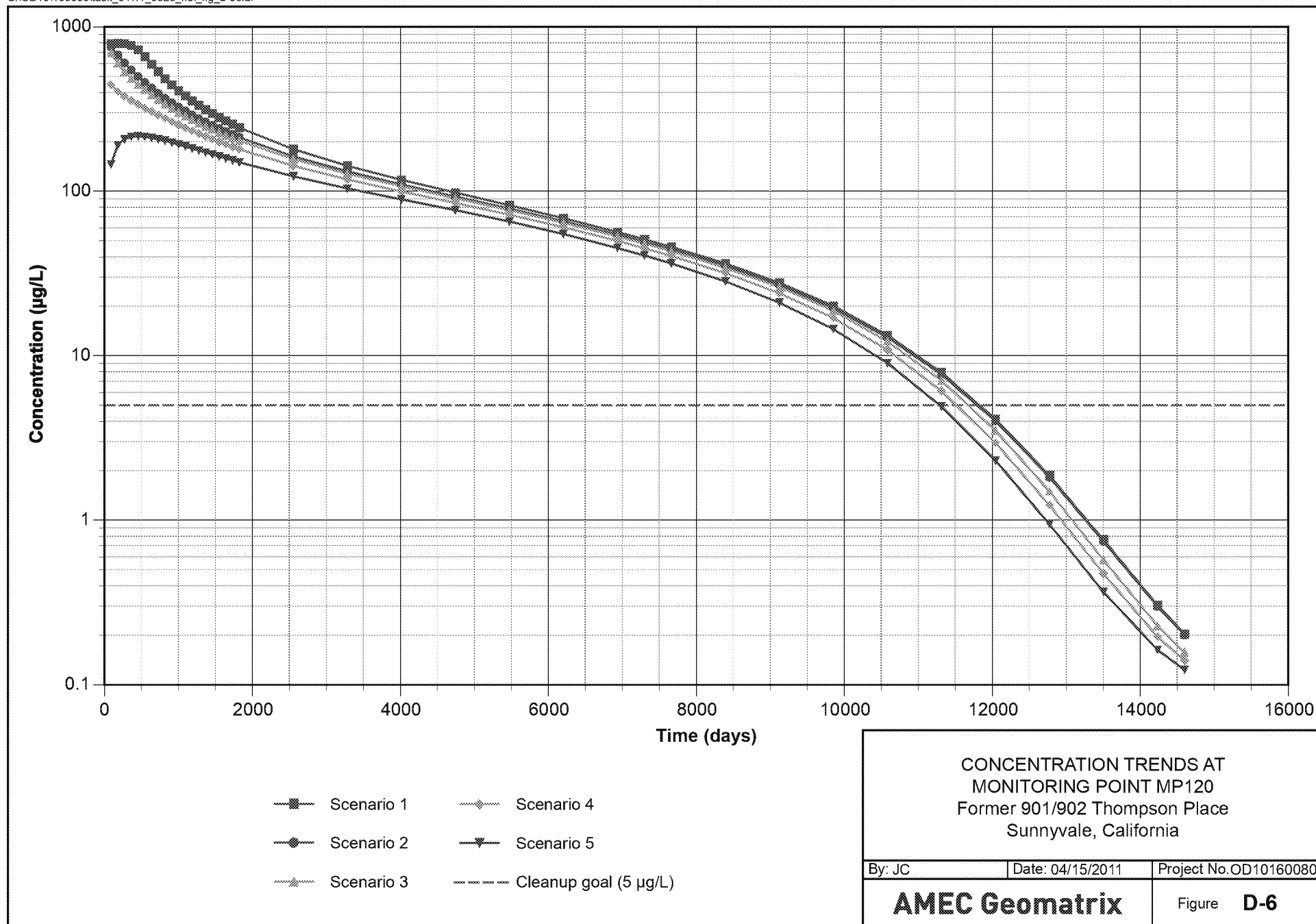
Project No. OD10160080

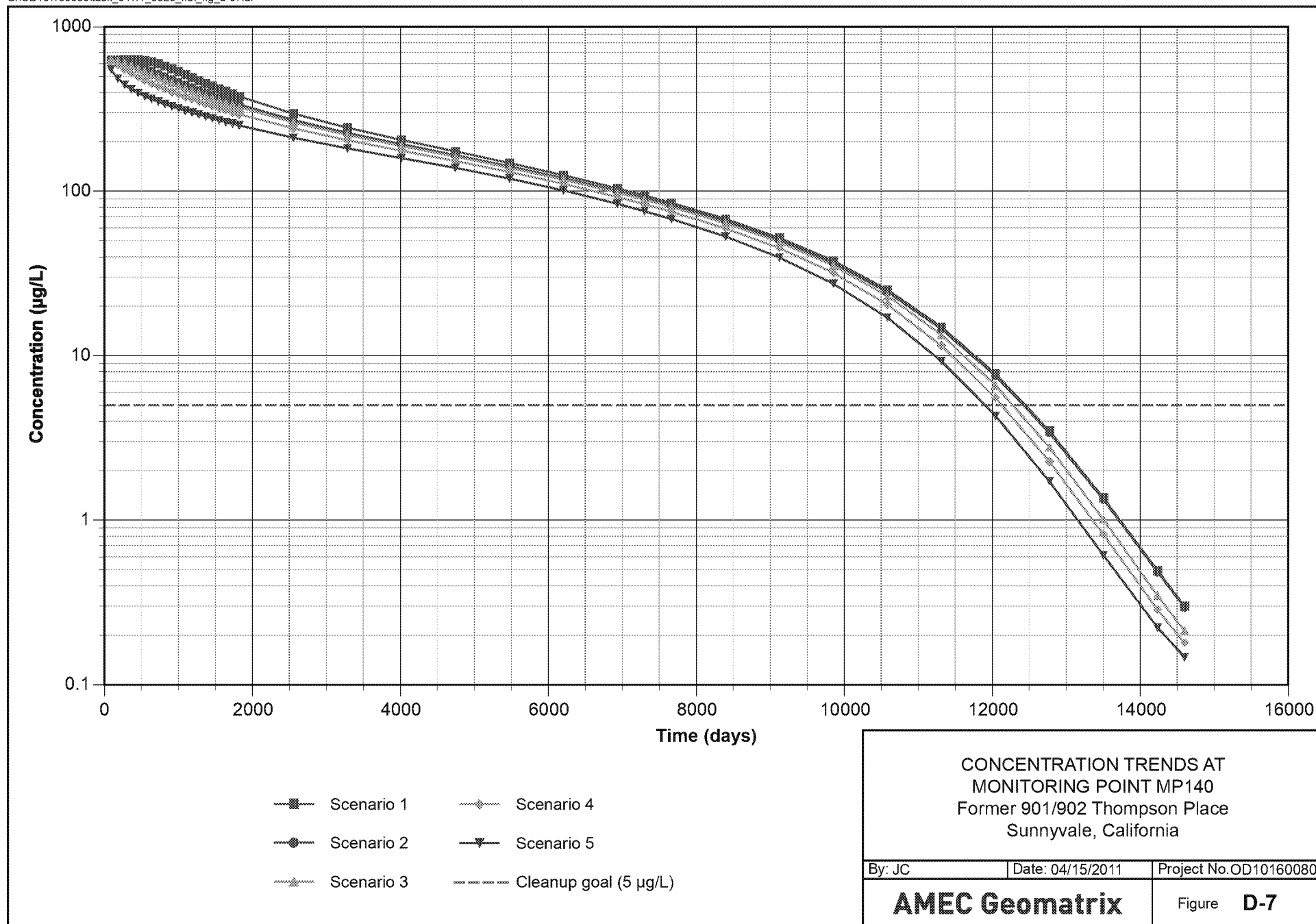
**AMEC Geomatrix**Figure **D-2**

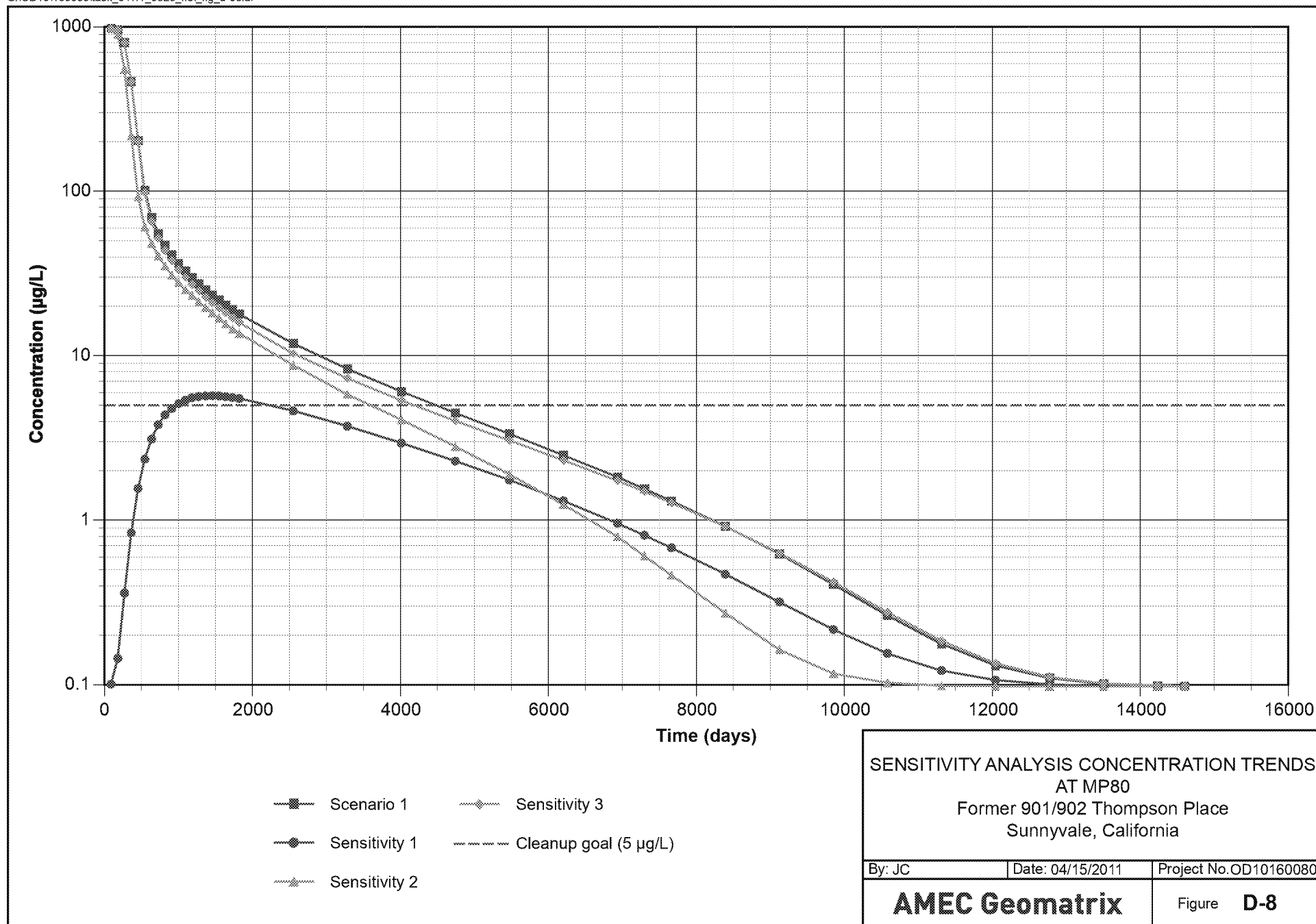












---

**APPENDIX E**

Cost Estimates



**TABLE E-1**

**ALTERNATIVE 1: NO FURTHER ACTION**

Former 901/902 Thompson Place  
Sunnyvale, California

Task	Quantity	Unit	Annual Cost	Comment
None	1	Annual Cost	\$0	Baseline scenario
Present Value of Cumulative Cost <sup>2</sup> (30 Years, 7% discount)			<u>Total Amount</u>	
			\$0	

**TABLE E-2**

**ALTERNATIVE 2: GROUNDWATER EXTRACTION AND TREATMENT**

Former 901/902 Thompson Place  
Sunnyvale, California

Task	Quantity	Unit	Annual Cost	Source
Groundwater Extraction and Treatment <sup>1</sup>	1	Annual O&M Cost	\$95,220	AMEC pump and treat system <sup>2</sup>
Annual Groundwater Sampling	1	Annual Monitoring Cost	\$20,000	AMEC 2010 annual cost <sup>3</sup>
<b>Present Value of Cumulative Cost <sup>4</sup> (30 Years, 7% discount)</b>			<b>Total Amount</b>	
			<b>\$1,529,854</b>	

**Notes**

1. Pump-and-treat system assumes use of two vessels, at 2,000 pounds each, of granular activated carbon and an average extraction rate of 24 gpm.
2. Annual cost of \$95,220 is based on 90% of the baseline O&M cost of \$82,000, excluding carbon changeout, incurred in 2009 for a similar system with an average extraction rate of 50 gpm, plus three carbon changeouts annually (at \$3,000 each) and a 15% contingency.
3. Actual cost incurred in 2010 at the site.
4. The amount represents the net present value estimated using a 7% discount rate for 30 years.

TABLE E-3

**ALTERNATIVE 3: MONITORED NATURAL ATTENUATION  
AND REDUCED GROUNDWATER EXTRACTION AND TREATMENT**

Former 901/902 Thompson Place  
Sunnyvale, California

Task	Quantity	Unit	Annual Cost	Source
Groundwater Extraction and Treatment <sup>1</sup>	1	Annual O&M Cost	\$82,340	AMEC pump-and-treat system <sup>2</sup>
Annual Groundwater Sampling	1	Annual Monitoring Cost	\$20,000	AMEC 2010 annual cost <sup>3</sup>
<b>Present Value of Cumulative Cost <sup>4</sup> (30 Years, 7% discount)</b>			<b>Total Amount</b>	
			<b>\$1,358,837</b>	

**Notes**

1. Pump-and-treat system using two vessels, at 2,000 pounds each, of granular activated carbon with an average extraction rate of 12 gpm.
2. Annual cost of \$82,340 is based on 80% of the baseline O&M cost, excluding carbon changeout, of \$82,000 incurred for a similar system with an average extraction rate of 50 gpm, plus two carbon changeouts annually (each costs \$3,000) and a 15% contingency.
3. Actual cost incurred in 2010 at the site.
4. The amount represents the net present value estimated using a 7% discount rate for 30 years.

**TABLE E-4**

**ALTERNATIVE 4: IN SITU BIOREMEDIATION**

Former 901/902 Thompson Place  
Sunnyvale, California

Task	Quantity	Unit	Annual Cost	Source
In Situ Bioremediation <sup>1</sup>	1	Annual Implementation Cost	\$80,500	U.S. EPA Third Five-Year Review <sup>2</sup>
Present Value of Cumulative Cost <sup>3</sup> (7 Years, 7% discount)			<b>Total Amount</b> <b>\$464,206</b>	
Quarterly ISB Performance Monitoring <sup>4</sup>	1	Annual Monitoring Cost	\$50,000	AMEC 2010 Annual Cost <sup>5</sup>
Present Value of Cumulative Cost <sup>3</sup> (10 Years, 7% discount)			<b>Total Amount</b> <b>\$288,327</b>	
Annual Groundwater Sampling <sup>6</sup>	1	Annual Monitoring Cost	\$20,000	AMEC 2010 Annual Cost <sup>5</sup>
Present Value of Cumulative Cost <sup>3</sup> (15 Years, 7% discount)			<b>Total Amount</b> <b>\$194,909</b>	
<b>Total Present Value</b>			<b>\$947,443</b>	

**Notes**

1. The alternative assumes active in situ bioremediation (ISB) for the first 7 years.
2. Average cost from 2004 to 2008 was \$140,000, minus the annual groundwater monitoring and ISB performance monitoring cost, plus a 15% contingency.
3. The amount represents the net present value estimated using a 7% discount rate.
4. This alternative assumes quarterly ISB performance monitoring for the 10 years.
5. Actual cost incurred in 2010 at the site.
6. Annual groundwater sampling occurs for a period of 15 years.

**TABLE E-5a**

**ALTERNATIVE 5: PERMEABLE REACTIVE BARRIER**

Former 901/902 Thompson Place  
Sunnyvale, California

Task	Quantity	Unit	Total Capital	Source
PRB Installation	1	Capital Cost	\$1,168,664	based on the PRB cost for a nearby project performed by Geomatrix Consultants, Inc. <sup>1</sup>
<b>Operations and Maintenance</b>			<b>Annual Cost</b>	
Annual Groundwater Sampling	1	Annual Monitoring Cost	\$20,000	AMEC 2010 annual cost <sup>2</sup>
Present Value of Cumulative Cost <sup>3</sup> (30 Years, 7% discount)			<b>Total Amount</b> <b>\$265,553</b>	
Semiannual PRB Performance Monitoring	1	Annual Monitoring cost	\$40,000	based on the annual groundwater monitoring <sup>4</sup>
Present Value of Cumulative Cost <sup>3</sup> (30 Years, 7% discount)			<b>Total Amount</b> <b>\$531,107</b>	
<b>Total Present Value</b>			<b>\$1,965,324</b>	

**Notes**

1. Boring is 36 inches in diameter, effective capture width is 1.7 times the diameter, 150 lineal feet of PRB, 30 borings, with 20% safety factor, 36 borings in total, 50% ZVI, 30% sand, and 20% activated carbon. See Table E-5b for details.
2. Actual cost incurred in 2010 at the site.
3. The amount represents the net present value (NPV) estimated using 7 percent discount rate.
4. PRB performance monitoring assumes the amount of samples collected semiannually is the same as for annual groundwater monitoring.

TABLE E-5b

**ALTERNATIVE 5: CAPITAL COST DETAILS FOR PERMEABLE REACTIVE BARRIER**

Former 901/902 Thompson Place  
Sunnyvale, California

Item Description	Unit	Unit Cost	Quantity	Cost	Sub-Total	Task Total
<b>Task A: PRB Design and Work Plan Submittal</b>						
<b>Geomatrix Scope of Work:</b>						
Design system	lump	\$ 7,434	1	\$ 7,434		
Design report to RWQCB	lump	\$ 11,150	1	\$ 11,150		
<b>Task A Total</b>					<b>\$</b>	<b>18,584</b>
Item Description	Unit	Unit Cost	Quantity	Cost	Sub-Total	Task Total
<b>Task B: PRB Installation</b>						
<b>36 ZVI borings<sup>1</sup></b>						
<b>Geomatrix Scope of Work:</b>						
Project management; final design; prepare RFBs;	lump	\$ 30,150	1	\$ 30,150		
Final design	lump	\$ 13,900	1	\$ 13,900		
Prepare RFBs	lump	\$ 7,115	1	\$ 7,115		
Procure equipment and materials	lump	\$ 9,085	1	\$ 9,085		
Oversight of delivery, mixing, and storage of materials	lump	\$ 4,110	1	\$ 4,110		
Install LDPCs (36 borings, 1.5/day, plus contingency days)	lump	\$ 48,332	1	\$ 48,332	\$112,692	
<b>PRB Installation—Subcontractor—Drilling, and Waste Disposal</b>						
Malcolm Drilling Estimate - mob/demob	lump	\$ 65,000	1	\$ 65,000		
Drilling per boring	each	\$ 10,000	36	\$ 360,000		
Zaccor Company site prep: excavation and demo	each	\$ 10,000	1	\$ 10,000		
Waste disposal (soil non-haz; Clearwater Quote)	ton	\$ 40	830	\$ 33,200		
Waste disposal (water non-haz; Clearwater Quote)	lump	\$ 30,000	1	\$ 30,000	\$498,200	
<b>LDPC Installation—Materials</b>						
ZVI	ton	\$ 650	310	\$ 201,500		
ZVI royalty = 15% of ZVI and drillers cost	each	\$ 93,975	1	\$ 93,975		
activated carbon	ton	\$ 566	24	\$ 13,584		
sand	yard <sup>3</sup>	\$ 100	285	\$ 28,500	\$337,559	
<b>Reimbursables</b>						
Field vehicle	month	\$ 1,800	1	\$ 1,800		
gloves, decon supplies	week	\$ 20	4	\$ 80		
expendables	day	\$ 20	25	\$ 500		
sounder	day	\$ 25	25	\$ 625	\$3,005	
<b>Task B Total</b>					<b>\$</b>	<b>951,456</b>

TABLE E-5b

**ALTERNATIVE 5: CAPITAL COST DETAILS FOR PERMEABLE REACTIVE BARRIER**

Former 901/902 Thompson Place  
Sunnyvale, California

Item Description	Unit	Unit Cost	Quantity	Cost	Sub-Total	Task Total
<b>Task C: Installation of Performance Monitoring Wells</b>						
<b>Geomatrix Scope of Work:</b>						
Pre-field	lump	\$ 9,380	1	\$ 9,380		
Design monitoring well construction	lump	\$ 5,880	1	\$ 5,880		
Installation of 24 wells, 3 depths per well	lump	\$ 32,200	1	\$ 32,200		
Develop wells	lump	\$ 12,400	1	\$ 12,400		
Logs and well construction reporting	lump	\$ 11,640	1	\$ 11,640	\$ 71,500	
<b>Well Installation—Subcontractor and Materials</b>						
Direct-push contractor	day	\$ 3,000	24	\$ 72,000		
technician to build multilevel wells	hour	\$ 90	48	\$ 4,320		
mob/demob	hour	\$ 125	16	\$ 2,000		
steam cleaner	day	\$ 95	24	\$ 2,280		
Well materials (sand/cement)	foot	\$ 2	960	\$ 1,920		
Well supplies	each	\$ 250	24	\$ 6,000		
LDPE tubing	foot	0.20	1,000	\$ 200		
drums	each	\$ 45	48	\$ 2,160		
inertial pumps	each	\$ 30	72	\$ 2,160		
Waste disposal (non-haz; Clearwater Quote)	drum	\$ 250	48	\$ 12,000	\$105,040	
<b>Reimbursables</b>						
Field vehicle	month	\$ 1,800	1	\$ 1,800		
Field supplies and equipment	day	\$ 40	25	\$ 1,000		
water quality kit	day	\$ 75	12	\$ 900	\$3,700	
<b>Task C Total</b>						<b>\$ 180,240</b>
<b>Task D: Implementation Report</b>						
<b>Geomatrix Scope of Work:</b>						
Report prep	lump	\$ 12,869	1	\$ 12,869		
Review	lump	\$ 5,515	1	\$ 5,515		
<b>Task D Total</b>						<b>\$ 18,384</b>
<b>Total Capital Cost</b>						<b>\$ 1,168,664</b>

**Notes**

1. Boring is 36 inches in diameter, effective capture width for each boring is 1.7 times the diameter based on Freethey et al. (2002).